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The effects of halving lost and wasted food on food security, water, land and fertilizer resources - A quantitative comparison between developed and less developed regions

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ABSTRACT

Addressing the problem of food losses and wastes has gained much attention in recent years as a solution to the problem of global hunger and food insecurity. However, most studies on the issue occurred in developed nations. This study quantifies the effects of halving lost and wasted food in less developed and developed countries, and estimating the effects of such reduction on food security and resources used to produce it. The study used data from the Food and Agriculture Organization (FAO) food balance sheets, and resources for 2013 and 2014. The data included 172 countries and 69 food types. All calculations were made at the crop level and aggregated to country and regional levels. The study analyzed seven regions including less developed and developed countries. The results compared lost and wasted food quantities by regions, and converted them into calories to enable the estimation of the effects on food security using a direct calculation and the FAO methodology for estimating food insecurity. The same quantities were used to calculate the amount of land, water and fertilizers used to produce wasted and lost food.

The results reveal that developed regions lost and wasted more meat and dairy than less developed regions by a wide margin, while less developed regions lost and wasted more of the remaining categories. In general, less developed regions lost and wasted more food both in quantities and calories, resulting in more lost and wasted water, land and fertilizer than developed regions. The study concluded that reducing food losses and wastes would save more food and resources in less developed than developed regions, and enable less developed regions

to feed 87% to more than 100% of food insecure people in this region in 2013, while developed regions could feed their food insecure populations more than three times over using their food savings alone. The study recommends focusing on obtaining better data and reducing food wastes and losses in regions that need it the most, especially Sub-Saharan Africa, South and South East Asia and Latin America and the Caribbean.

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CHAPTER 1: INTRODUCTION, OBJECTIVES AND GENERAL BACKGROUND

1.1. Introduction of the problem

Human societies throughout their existence have recognized the importance of access to adequate food through continuous improvements in the ability to produce more food, which allowed humans to move from hunter-gatherers to farmers and to current agricultural technologies (Diamond, 1987; Mazoyer and Roudart, 2007; Alston at al. 2009). History however, shows that hunger has really never gone away. In the last century, hunger and famines have been commonplace due to lower yields, unpredictable weather patterns, inefficient agricultural technologies, wars and political unrest, climate change, poor agricultural policies and many other reasons that have weakened communities and societies globally, but relatively more so in less developed countries (Sanchez, 2002; Parry at al. 2009; Mueller et al., 2012; Garnett et al. 2013). Reducing hunger continues to be a pressing issue in many countries as food production is no longer viewed as an isolated activity, but rather a system connected to other pressing issues like soil loss, water use and pollution, environmental degradation, deforestation, and climate change (Power, 2010; Foley et al. 2011). The issue of feeding the global population solely through producing more is compounded considering its effects on the environmental system.

The unsustainable growth rate of the global population has turned food security into an even more complex dilemma (Godfray et al. 2010; Tscharntke et al. 2012). The United Nations

Population Division's urbanization forecasts and the world population prospects estimate that the global population will exceed 9.5 billion people by 2050 (Alexandratos and Bruisma, 2012; United Nations, 2014). The majority of this increase will be in less developed countries, which are expected to host approximately 8.25 billion people alone (United Nations, 2013). The need to produce food and space for residential and other uses will increase the scarcity of natural resources and may increase the scale of deforestation, freshwater use, and overfishing, and will likely increase the number of endangered species and rate of air and water pollution (Mekonnen & Hoekstra, 2016; Das Gupta, 2014; FAO, 2011; UNEP, 2006). Nonetheless, studies by Alexandratos and Bruinsma (2012) and Food and Agriculture Organization of the United Nations (FAO, 2013) estimated that agricultural productivity will have to increase by 70% by 2050 to meet the food demand of the world's population. While increasing agricultural productivity is still a viable approach, balancing its requirements with global concerns on the environment requires including other approaches that can facilitate the global efforts to eradicate hunger. These approaches include reducing food losses and food wastes which would presumably increase food availability and enable nations to eradicate hunger without the need to increase natural resource use or at least reduce the rate of increase.

1.2. Food loss and food waste: Definitions and history

In their FAO report, Gustavsson et al. (2011) defined food waste and food loss as: "food wasted or lost is measured only for products that are directed to human consumption, excluding feed and parts of products that are not edible". Therefore, food losses and wastes are the masses of food, lost and wasted during the stages of food supply chain for “edible food products for human consumption.” In other words, food originally produced to feed humans that leaves the human food chain represents food loss or food waste, even if it is directed to a non-food use (e.g., feed, bioenergy). Similarly, Parfitt et al. (2010) defined food loss as “the reduction of edible food mass during the process of food supply chain” and noted that “this process includes production, postharvest and processing, while food losses happening towards the end of the food supply chain such as retail, restaurants and hotels, school and college cafeterias and household consumption represent food waste.”

Both studies and others insist that the production of food crops for biofuel and feed takes away so much that would otherwise be used to feed the hungry that these crops could be considered as food lost to humans (Parfitt et al., 2010, Pimentel et al., 2009; Tscharntke et al., 2012; Rathmann, Szklo, and Schaeffer, 2010; Engdahl, 2008; Tangermann, 2008; Msangi, Sulser, Rosegrant, and Valmonte-Santos, 2007). Other studies, however, have argued that crops used for feed or even biofuels should not be considered food wastes or losses because feed eventually comes back in form of meat or dairy, and most crops used for biofuels were not intended for human consumption or were produced on marginal lands, not forgetting that food security is not solely caused by biofuel but other causes such as poverty and poor infrastructure (Rathmann, Szklo, and Schaeffer, 2010; Ajanovic, 2011; Tilman, Hill, and Lehman, 2006; Tilman et al., 2009).

According to the Swedish Institute for Food and Biotechnology (SIK), global losses and wastes of food for humans accounted for about one-third of all food produced in 2007, or the equivalent of 1.3 billion tons of food (Gustavsson et al., 2011). Similarly, estimates by Lipinski et al., (2013) suggested that 32% and 24% of global production measured in weight and calories, respectively, was lost or wasted to humans in 2009. In Europe, an estimated 179 kg of food per capita corresponding to 89 million tons of food per year was wasted in 2009 (Monier et al., 2011). Other estimates by Foley et al. (2011) indicate that half of all food produced for human consumption was lost globally. The extent of this food waste and loss is different from region to region. FAO estimates that in developed/ industrialized countries as in North America and Europe, the per capita food waste is about 95 to 115 kg per year, while in less developed countries such as Sub-Saharan Africa and South and Southeast Asia, the amount of food wasted per capita is 6 to 11 kg per year (Gustavsson et al., 2011). In addition, Buzby and Hyman (2012) estimated that in 2008, United States consumers wasted about 124 kg of food per consumer, which was equivalent to $390 and represented about 10% of the average expenditure on food per person.

Although food waste at the consumer level is very low in less developed countries, food loss in processes prior to the consumer stage is enormous. Wilson's report mentioned that these losses often constitute 50% or more in less developed countries while they can be between 10 to 40% in developed countries (Wilson, 2013; FAO, 2013). The World Bank reported that the value of postharvest losses in Sub-Saharan Africa alone has reached an annual value loss of $4 billion for grains alone, the value of which far exceeds the total food aid received in that region over the last decade (World Bank, 2011; Affognon et al., 2015).

Some studies have focused on converting this waste and loss into nutrient loss such as calories and found that after the conversion, the wasted and lost food globally presented in the FAO estimates represents about 24% of all food calories produced (Lipinski et al., 2013). All the above studies also mention that it is important to distinguish where the loss occurs, in terms of regions, commodities, stages in the food supply chain and their share on a global scale. This makes it possible to devise plans of curbing them and makes it possible to see why some regions are more affected than others. For example, FAO (2011) estimated that in 2009, 1.5 quadrillion kilocalories (kcal) were lost or wasted, with 53%, 14% and 13% of this waste/loss from cereals, roots and tubers and fruits and vegetables respectively, accounting for 80% of kcal wasted globally and 83% of food wasted in tons (weight). The same study also estimated that about 80% of this waste came from Industrialized Asia, North America and Oceania and Europe.

The above studies shed light to wasted potential to feed the hungry while using resources efficiently. Currently, there is a concerted effort to reduce food losses and wastes in half by 2025 to 2030 for many countries (European Commission, 2012; USDA, 2015; UN SDG, 2015; Mourad, 2015). A 50% reduction in edible food wastes and food losses could presumably provide enough to feed people who are currently considered food insecure. This research seeks to examine the effects of halving lost and wasted food on food security through food availability and what effect this reduction could have on the natural resource (water, land) and fertilizer use.

1.3. Study objectives

The specific objectives of this research are to estimate the effects of halving food losses and wastes in developed and less developed regions on

1. Regional-specific food security through increased food availability and
2. Regional-specific water, land and fertilizer use.

The definitions of developed countries versus less developed countries can differ depending on the context and intent of the definer. In this study, only countries defined by *World Economic Situation and Prospects* (Outlook, 2014) as developed economies were classified as developed, while every other country (i.e., economies in transition and less developed economies) was classified as less developed countries.

1.4. Food security definitions

A number of definitions have been offered for food security. According to Maxwell and Smit (1992), more than 200 definitions of this term had been published by 1992. The concept of food security originated in the 1970s during discussions of a global food crisis with an initial focus on food supply problems –to ensure enough food availability and to some degree affordability of food prices for basic foodstuffs at the national and international level (Clay, 2002, Bruinsma, 2003).

The issues of famines, hunger, and food crisis examined in this time period resulted in a new definition of food security and re-emphasized the important aspects of vulnerable people across the globe. This led to the 1974 World Food Summit defining food security as “ the availability at all times of adequate world food supplies of basic foodstuffs … to sustain a steady expansion of food consumption … and to offset fluctuations in production and prices” (United Nations, 1975). The FAO and World Bank later expanded this definition to “Ensuring that all people at all times have both physical and economic access to the basic food that they need’ (FAO, 1983) and enough of it to ‘ensure an active, healthy life” (World Bank, 1986). This definition also emphasized that both supply – availability of food through production, stock, and imports, and demand – consumption, access to the available food, and purchasing power of consumers, are important for food security to happen (Sen, 1981).

Before this definition was agreed upon, the original meaning of food security was that of a country that has access to enough food that meets the required dietary energy. National food security meant that the country was self-sufficient and that it could produce enough food for its population. This definition lacked clarity, however, as to whether this self-sufficiency included access by all people in the country to enough food to meet energy and nutritional requirements or meeting economic demand from domestic production was enough to be considered self-sufficient. This left loopholes for nations to easily claim self-sufficiency when many people are food insecure (Pinstrup-Andersen, 2009).

In 1996, The World Food Summit expanded its definition again and added some complex attributes including: “Food security at the individual, household, national, regional and global levels is achieved when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life.” (FAO, 1996; Summit, 1996). The State of Food Insecurity of 2001 also refined the above definition to include”… social access to sufficient, safe and nutritious food…” (Bruinsma, 2003). The additions of words “safe, nutrition and food preference” emphasized the need for food safety, nutritional requirements and the move from simply accessing enough food to accessing enough preferred food. The United States Department of Agriculture adds that food security includes the ‘assured ability to acquire acceptable foods in socially acceptable ways, without resorting to emergency food supplies, scavenging, stealing or other coping strategies’ (USDA, 2007). As provided by Gustavsson et al. (2011), all the above definitions indicate that food security is when all people at all times have physical, social and economic access to sufficient, safe and nutritious food necessary to lead healthy and active lives.

Food security’s three most important components are: a) food availability encompassing production, distribution, and exchange; b) food access which includes affordability, allocation and preference; and c) food utilization which encompass nutritional value, social value and food safety (Gregory et al., 2005). These are instrumental in quantifying food security through various approaches to collect, document and analyze food security status of every nation or region (Babu et al., 2014). The food availability component addresses the supply side of the food security and requires that sufficient quantities of quality foods from domestic agricultural production, food stocks, imports, and exports are enough and available for the people in need of food in a country or region. Food wastes and losses significantly impact this component because 40% of all food produced for human consumption is lost before it reaches the market in less developed countries (Godfray et al., 2010; Wilson, 2013), effectively reducing availability and increasing food prices.

The food access component encompasses income levels, expenditures and buying capacity of households or individuals. Food access could be physical access in the market or economic access to food by the individual or the household (Babu et al., 2014). Physical access may be determined and limited by factors such as infrastructure and market outlets, while economic access depends on the ability of consumers to purchase the available food, income levels, and the existing food prices, which could depend on the existing physical availability to food (Thomson and Metz, 1999). Food wastes and losses are important in less developed countries where incomes are much lower and expenditures for food comprise a larger portion of household income (Lam, 2011; Parfitt et al., 2010). Thus, a small change in income or food price creates a large effect on food security. Research has shown that enough food is often available but inaccessible by poor people globally because of food prices (Bhattacharya et al., 2004). On the other hand, incomes in developed nations are relatively higher and expenditure on food is a much lower component of income. As a result, more than 85% of people in these regions are considered food secure, and those who are food insecure live in low-income households. In addition, high incomes may be at the root of food waste, especially in developed countries (Bloom, 2010; Stuart, 2009; Sibrian et al., 2006). Even in developed countries such as the United States of America and European Union countries, where enough food for human consumption is produced and 40% of it is wasted, many households and individuals remain food insecure (Coleman-Jensen, 2014), and many more are overweight and obese due to overconsumption of food and unhealthy eating habits (FAO, 2017, WFP, 2017).

Food utilization emphasizes the nutritional outcomes of an individual or household and depends on that individual or household's ability to properly cook and prepare food, using diverse diets and applying feeding and caring practices properly (Torun et al., 1996; Holt-Giménez and Peabody, 2008). Food wastes and food losses are linked to this component through both the quantity and quality lost because poor preparation of food can lead to some of it being thrown away or its quality lost in the process of preparation. Low availability, accessibility and proper utilization of good quality food are the major causes of lower nutrient intakes both in developed and less developed countries and reducing the food wastes and losses may have a positive impact on this component.

1.5. Effects on food availability and food security

While the food was being lost or wasted, globally about one billion people faced hunger and two billion people were suffering from hunger and malnutrition in 2010 (Chappell and LaValle, 2011). The issue of wasting food according to Bräutigam et al. (2014) can be traced to ethical problems with consumer behavior in industrialized countries and is linked to hunger and rural poverty in less developed countries. The careless handling of food in developed countries is associated with the increase in the global demand for food through increased food prices, thereby increasing food insecurity in less developed countries. In addition, saving food that is currently wasted or lost and redistributing it to the regions and people in need of it could improve food security and feed around 1.9 billion people in terms of kcal, assuming 2100 kcal per capita per day, more than twice the number of hungry people today (Kummu et al., 2012). According to estimates by Stuart (2009), North America and Europe discarded 30 to 50% of their food supplies, enough to feed the world's hungry three times over.

If 50% reduction of this waste was achieved and redistributed to the hungry, it could feed all the food insecure people. The analysis by Lipinski et al. (2013) suggested that cutting the global rate of food loss and waste by half would close roughly 22 percent of the 6,000 trillion kcal per year gap between food available today and that needed in 2050. The same reduction rate was estimated to potentially reduce the required food production by approximately 25% of the current production, assuming that 30% of globally produced food is wasted (Foresight, 2011). In Sub-Saharan Africa, the amount of food lost before the market has been estimated to have enough caloric value to feed 48 million people (World Bank, 2011), which would reduce requirements to produce more. Munesue et al. (2015) assessed changes in food insecurity in less developed countries as a result of a 50% reduction in food wastes by developed countries and found that assuming no changes in incomes, this reduction would reduce the number of undernourished people in less developed countries by approximately 63.3 million, or approximately 7.4% of undernourished people globally in 2007. This study did not consider the amount of lost food in these less developed countries, meaning that if this action was taken globally, the estimates of quantities available could be more than 63.3 million.

All of these studies demonstrate that saving wasted food even by a small percentage can impact food security substantially, assuming that it is redistributed to those in need. The challenge for policy-makers has been to make agriculture's response to increased demand both economically efficient and environmentally sustainable (Garnett et al., 2013). This is only a part of the problem, however, as Aschemann-Witzel et al. (2018) has indicated, a growing middle class will complicate this issue due to expectations of complete supermarket assortments, throwing away foods that are close to expiration dates or do not meet aesthetic expectations (Van Boxstael et al., 2014; Loebnitz et al., 2015; Loebnitz and Grunert, 2015). In addition, current marketing practices that provide offers such as buy one get one free or at half price encourage over consumption (Qi and Roe, 2016; Schmidt, 2016).

The above factors pertain to social and individual consumer preferences, characteristics and behaviors which are much more difficult to legislate, requiring consumer awareness campaigns to reach individuals (Chalak et al., 2016). Consumer campaigns have been shown to be efficient, yet awareness of the food waste problem is only high in countries where the media has prioritized it (Neff et al., 2015; Aschemann-Witzel et al., 2015; Aschemann-Witzel et al., 2018). This leads to consumers in more developed countries learning about the issue, while those in emerging economies and less developed countries remain unaware of the situation not only because of less coverage, but also because research and data on the issue are scarce (Xue et al., 2017). In addition, any available research and data on this issue are focused on the latter stage of food supply chains, which are not developed or are simply nonexistent in less developed countries (Balaji and Arshinder, 2016; Naziri et al., 2014), ignoring the losses at prior stages. Others focused on certain food types and categories like perishables and certain sectors such as the hospitality sector (Song et al., 2015; Liu et al., 2016; Painter et al., 2016; Papargyropoulou et al., 2016; Henz, 2017; Henz and Porpino, 2017).

While a small number of studies exist for specific less developed countries, Aschemann-Witzel et al. (2018) and Bekin et al. (2007) found that very few studies have explored Latin America or Sub-Saharan Africa, or compared developed and less developed countries or different regions. And unless these approaches are consumer- or individual-initiated, their efficiency may be reduced due to skepticism of public and government institutions (De Koning et al., 2015) and their failure could increase reliance on convenience foods which will likely encourage more food waste behavior in addition to unhealthy eating habits (Mallinson et al., 2016).

1.6. Effects on resources and environment

The effects of food wastes and losses are not limited to food security but also extend to the waste of resources used to produce them and the future ability of feeding the world population by freeing up finite resources for other uses, and decreasing environmental risks and financial losses (Munesue et al., 2015, Bräutigam et al., 2014). When food is lost or wasted, the resources used to produce it are also wasted or lost. These include land, water, energy, fertilizers, pesticides, and labor. In addition, food waste and loss present a double effect as it adds pressure to the environment in terms of landfills and greenhouse gases and the cost to clean them.

Agriculture is the major producer of greenhouse gas emissions, water quality degradation from soil loss and nutrient runoff, and water use (West et al., 2014). Irrigation for agriculture accounts for 70% of global water withdrawals and 90% of water consumption, while approximately one third of terrestrial lands have agricultural crops or planted pastures as a dominant land use and another 10 to 20% of land is under intensive livestock grazing (Vermeulen et al., 2012; Gleick et al., 2009; Scherr & McNeely, 2008; Scherr & Sthapit, 2009). Globally, about 20% of irrigation and 24% of freshwater used for agriculture are wasted through food supply chains' losses (Kummu et al., 2012). The global consumption of natural resources used to produce wasted food was estimated at approximately 250 km^3 of surface and fresh water, and 1.4 billion hectares of land which is equivalent to 30% of the land area that is globally under agriculture (Munesue et al., 2015). In the United States alone, food production occupies 50% of the land, consumes 80% of all freshwater and 10% of the total energy, but 40% of the food produced, goes uneaten and ends up in landfills that produce approximately 25% of the total US methane emissions (Gunders, 2012).

In addition, FAO (2013) reported a global food waste of 1.6 gigatons (Gt) of primary products, which resulted in approximately 3.3 Gt of CO_2-equivalent of carbon emissions without including GHG emission from land use change. Other studies of food waste and food loss have revealed that vegetables, fruits, and bakery products represent the highest percentage of wasted food, but meat products consume more resources and emit more GHG, beef being the most consumptive (Fritsche et al., 2007; Lee and Willis, 2010; Venkat, 2011; Noleppa and Von Witzke, 2012; FAO, 2013). It has been estimated that reducing the current global food waste of 30% by half could reduce the food required in 2050 by about 25% of current production and save one hundred million acres of cropland (Dobbs et al., 2011, Foresight, 2011).

1.7. The calls to halve food wastes and losses to ensure food security

While calls to end hunger and food insecurity have been issued for decades, the push to reduce food waste and food losses is relatively recent. In fact, most of the efforts have been to increase food production as an effort to increase food security. This led to the period from 1960 to 2000 being accompanied by many innovations in agricultural productions and a decline in world food prices, but this period also brought extreme waste and loss of food. The first call to reduce food losses was the 1975 UN resolution that called for halving the amount of post-harvest losses over the next decade (Stuart, 2011). Six years after the resolution, an FAO report (1981) argued that it is much less expensive to reduce food waste and food losses than to produce more to offset the losses, although the report received little recognition.

With the increase in food prices between 2003 and 2008, subsequent events of hunger in many parts of the world coinciding with new projections of global populations exceeding 9.5 billion by 2050, and concerns of climate change and the effects on capabilities to feed all people, the issue of food losses and food waste became a central topic for many countries. In 2012, for example, the Japanese government introduced a policy aimed at reducing an estimated eight million tons of Japan's edible food that was wasted annually. This was equivalent to annual rice production by weight in Japan (Ikefuchi, 2007; MAFF, 2013). In the same year, the European Parliament called for efforts to cut in half food wastes by 2025 and named 2014 as the "European year against food wastage" (European Commission, 2012). In September 2015, the United States Department of Agriculture Secretary, Tom Vilsack, also called for halving food wastes and food losses by 2030 in the United States (USDA, 2015). Since then other countries and institutions have taken similar steps to reduce their own food and drink wastes. The United Nations meeting on September 25, 2015, adopted a similar goal as part of its new Sustainable Development Goals (SDGs) signed by 189 countries. The goal of halving global food wastes and losses was outlined in its 12th SDG for sustainable production and consumption (SDGs, UN, 2015). This set a precedent and perhaps was the first of its kind to include food losses and food wastes reduction within global development goals (Food Tank News, September 2015). France and Italy have also vowed to cut in half the amount of food wasted. France passed a law in 2016 banning supermarkets from throwing away or destroying unsold food as it approaches its sell–by or best before dates. The law instead forces supermarkets to donate it to charities and food banks (Mourad, 2015; The Guardian, 2016). This law also forbids supermarkets from spoiling food intentionally to stop it from being eaten by people foraging in stores garbage bins.

In the United States, bills such as the Emerson Good Samaritan Food Donation Act, Internal Revenue Code 170(e) (3), and the U.S. Federal Food Donation Act of 2008 have encouraged food donations to those in need. These bills have provided liability protection and tax incentives to donors, and allocated funds to support the efforts of reaching communities. These were enacted so that people in all regions and social and economic backgrounds in the U.S. may not face food insecurity (Cohen, 2006). These bills have encouraged efforts by major food companies, small and private firms, universities and colleges, sports teams and entertainment resorts to donate their food leftovers (Foderaro, 2009; Lipinski et al., 2013; Kim & Morawski, 2012).

1.8. Achievements in reducing global hunger and food insecurity

A great deal of progress has been made since the 1996 World Food Summit call for halving the number of undernourished people by 2015 (FAO, 1996; Summit, 1996). That goal was adopted as one of the Millennium Development Goals (MDG) articulated in September 2000 by 189 countries agreeing to adopt "UN Millennium Declaration to reduce poverty, improve health and promote peace, human rights, and environmental sustainability" (UNDP, 2003; McDonald, 2008). More specifically, target 1c of this declaration was to reduce the number of people who suffer from hunger by one-half. Table 1 presents the change in the number and percentages of food insecurity from 1990 to 2016.

Table 1. Comparison of undernourishment between 1990-1992 and 2014-2016

Number (millions) and prevalence (%) of undernourishment				
Periods	1990-1992	1990-1992	2014-2016	2014-2016
Regions	(Millions)	(%)	(Millions)	(%)
World	1,010.6	18.6	794.6	10.9
Developed regions	20.4	< 5	14.8	< 5
Less developed regions	990.7	23.3	790.7	12.9
Africa	182.1	27.6	232.5	20.0
Sub-Saharan Africa	175.7	33.2	220.0	23.2
Asia	741.9	23.6	511.7	12.1
Eastern Asia	295.4	23.2	145.1	9.6
South-Eastern Asia	137.5	30.6	60.5	9.6
Southern Asia	291.2	23.9	281.4	15.7
Latin America & Carib.	66.1	14.7	34.3	5.5
Oceana	1	15.7	1.4	14.2
Source: FAO/IFAD/WFP, 2017. The State of Food Insecurity in the World in 2016				

As Table 1 presents, some regions like East Asia, South East Asia, Latin America and Caribbean region met this goal of halving hungry people in their regions, but Sub-Saharan Africa and South and Southern Asia are still faced with the highest prevalence of hunger (Mcguire, 2015). Although the percentage of undernourished individuals has been reduced, the number of individuals has actually increased in Sub-Saharan Africa, indicating that either the population increased faster or better data were not available. According to the United Nations (2015), 47% of the population of less developed countries lived on less than $1.25 a day in 1990, but this was reduced to 14% by 2015, and the number of people living in extreme poverty in that same period was reduced by more than half, from 1.9 billion to 836 million. Most of this progress occurred between 2000 and 2015, with the proportion of undernourished people in the less developed regions falling from 23.3% to 12.9% within the period of 1990-1992 to 2014-2016. Despite the enormous progress towards reducing the number of hungry and undernourished people in the world, FAO estimated that about 815 million people were still suffering from chronic undernourishment in 2016 (FAO, IFAD, UNICEF, WFP, and WHO. 2017). Also Table 1 shows that most hungry people were and still are in less developed countries, representing 13.5 percent of the population of less developed counties. In addition, there were an estimated 14.5 million people undernourished in developed countries (FAO, 2014; IFPRI, 2014 and Rosen et al., 2014).

The Millennium Development Goals (MDG) helped achieve much, although at an uneven rate between countries and regions. This reduction in the number of hungry people was to a large degree due to the rate of agricultural innovation, which was particularly high during the 1950s and 1960s, most notably due to the Green Revolution (Borlaug, 2002). In countries such as

Brazil, Mexico, India and the Philippines, where the Green Revolution was publicized as successful, yields are said to have doubled or tripled so that some countries could sufficiently feed their own populations, with a surplus for global markets (Evenson and Gollin, 2003). In addition, high yielding crop varieties, irrigation, and agrochemicals increased less developed country crop production from 800 million tons in 1961 to more than 2.2 billion tons by 2000 (FAO, 2011). The scientist credited with the Green Revolution, Norman Borlaug (Borlaug, 2002; Pingali, 2012), argued that if the cereal yields of the 1950s had not improved, the world would have needed about 1.8 billion more hectares of land of equal quality to feed the population in 2000, instead of the 600 million hectares actually needed.

Since the 1950s, however, other agricultural innovations and practices such as conservation agriculture and precision agriculture highlighted the goal of conserving soil properties that are necessary to maintain productivity and enhance efficiency by using site-specific knowledge to target rates of fertilizers, seeds, and chemicals (Bongiovanni and Lowenberg-DoBoer, 2004). These have shown many promises through their comparison with the traditional forms of farming and have provided higher yield levels while maintaining soil properties that are necessary for sustainable food production (FAO, 2001; FAO, 2008; Hengxin et al., 2008; Erenstein et al., 2008; Rockstrom et al., 2009; Pretty et al., 2006; Lambert et al., 2016; Lambert et al., 2013; Landers, 2007). In fact, during this period, global food production outpaced population growth in most regions (Matson et al., 1997), except Sub-Saharan Africa and Southeastern Asia, where production levels stagnated or decreased and remained below the global average for most crops (Nin-Pratt and Yu, 2008; Webber and Labaste, 2010).

Nevertheless, this increase reduced food insecurity even in Sub-Saharan Africa and Southeastern Asia enough to approach their MDG targets.

The MDGs ended in 2015 and have been replaced by the Sustainable Development Goals (SDG) in 2016 with a different set of goals. They are similar in some ways since both recognize the urgent need to feed the global population, eradicate hunger and, importantly for this study, recognize the role of food wastes and losses (SDGs, 2015; FAO, 2015; Francesco Burchi & Sarah Holzapfel, 2015; Loewe & Rippin, 2015). The United Nations' SDGs still recognize the need to increase food production, and this may still be a viable option. At the current population growth rate, however, and with agricultural soil fertility declining in many places and competition for land for other uses increasing, it is absolutely important that food wastes and losses are included in the global policy of ensuring food security for all.

1.9. Areas of intervention for food wastes and losses and food security

Food waste and food loss in developed countries occur mainly at the retail and consumer levels, while in less developed countries most of the losses happen at the farm and post-harvest level due to poor transportation; lack of storage and cooling facilities; and lack of processing, packaging, and market systems (FAO, 2012; Rayner & Lang, 2012). FAO (2012) detailed a number of causes and methods of food loss and waste prevention. Techniques for preventing food losses and food wastes during the final stages of food supply chain include selling closer to producers and consumers in some areas, creating markets for sub-standard foods, changing supermarket standards for high quality appearance of fresh products, facilitating public education and awareness, and providing cooling storage facilities and better infrastructure in less developed countries (Gustavsson et al., 2011).

Food security in a less developed country context includes investment in harvesting technologies, storage facilities, transportation, and processing which would reduce post-harvest losses. Several studies have concluded that there are enough resources such as land, water, fertilizer and farmers, but what is lacking is good agricultural policy and the political willingness to move towards sustainable development (IFAP, 2008; UN FAO, 2009). On the other hand, studies have indicated that the current rate of natural resources degradation will eventually decrease our current production level and limit our ability to meet the demand for food (Pinstrup-Andersen, 2012). Both of these statements make clear that developing sustainable global food systems requires addressing the social, political and technological factors that limit discussions and prevent consideration of alternatives.

While largely an issue for less developed countries, developed countries can face a lack of adequate food on a small scale. As shown in Table 1, the developed world had less than 5% of food insecure people in 2016. That percentage, however small, hides the fact that these still account for 14.7 million people in developed countries (FAO, IFAD, UNICEF, WFP and WHO. 2017). In the United States alone, the number of households who were food insecure for at least some time in 2016 totaled 15.6 million, and these included households with low and very low food insecurity. An additional 6.1 million households had severe low food insecurity (Coleman-Jensen et al., 2017). The numbers offered by FAO differ from those provided by specific national statistics because their surveys are conducted differently and they are analyzed by country-specific attributes, definitions, and levels of food insecurity.

Target 2.2 of the Sustainable Development Goals adds that it is important to focus on ending all forms of malnutrition, ranging from undernutrition to overweight and obesity. Failure to achieve a reduction in overweight and obesity among the population arises from the failure of the third component of food security - safety and preparation of food (FAO, 2017). This study also notes that many children are growing up in environments that encourage unhealthy food habits and no physical activities after consuming more energy than is needed or expected (IFAD, 2017; WFP, 2017 and WHO, 2017). This, in turn, has led to a continuous increase in the number of overweight and obese people around the world. Between 1980 and 2014, the number of obese people doubled to more than 600 million adults (IFAD, 2017; WFP, 2017; WHO, 2017 and FAO, 2017). The problem is more prevalent in regions of the developed world, most notably North America and Oceania and Europe, but the numbers are rising in all regions (FAO, 2017). The current literature notes that this trend will likely continue as consumption trends and transitions in dietary choices continue to expand from the rich and middle-income nations to less developed nations and as global incomes and the population of people living in cities rise, giving way to increased demand for meats, animal-based products and highly processed foods (Parfitt et al., 2010; Monteiro et al., 2013; Westhoek et al., 2014; De Koning et al., 2015; Shafiee-Jood and Cai, 2016; Jurgilevich et al., 2016; Zhang, 2016). While the problem of overweight and obesity is gaining more attention, few studies actually capture its effects on children and different genders. Brunner et al. (2010), for example, wrote that equality in gender roles has and will continue to encourage fewer food preparations and healthy eating habits and reliance more on convenience foods or fast foods.

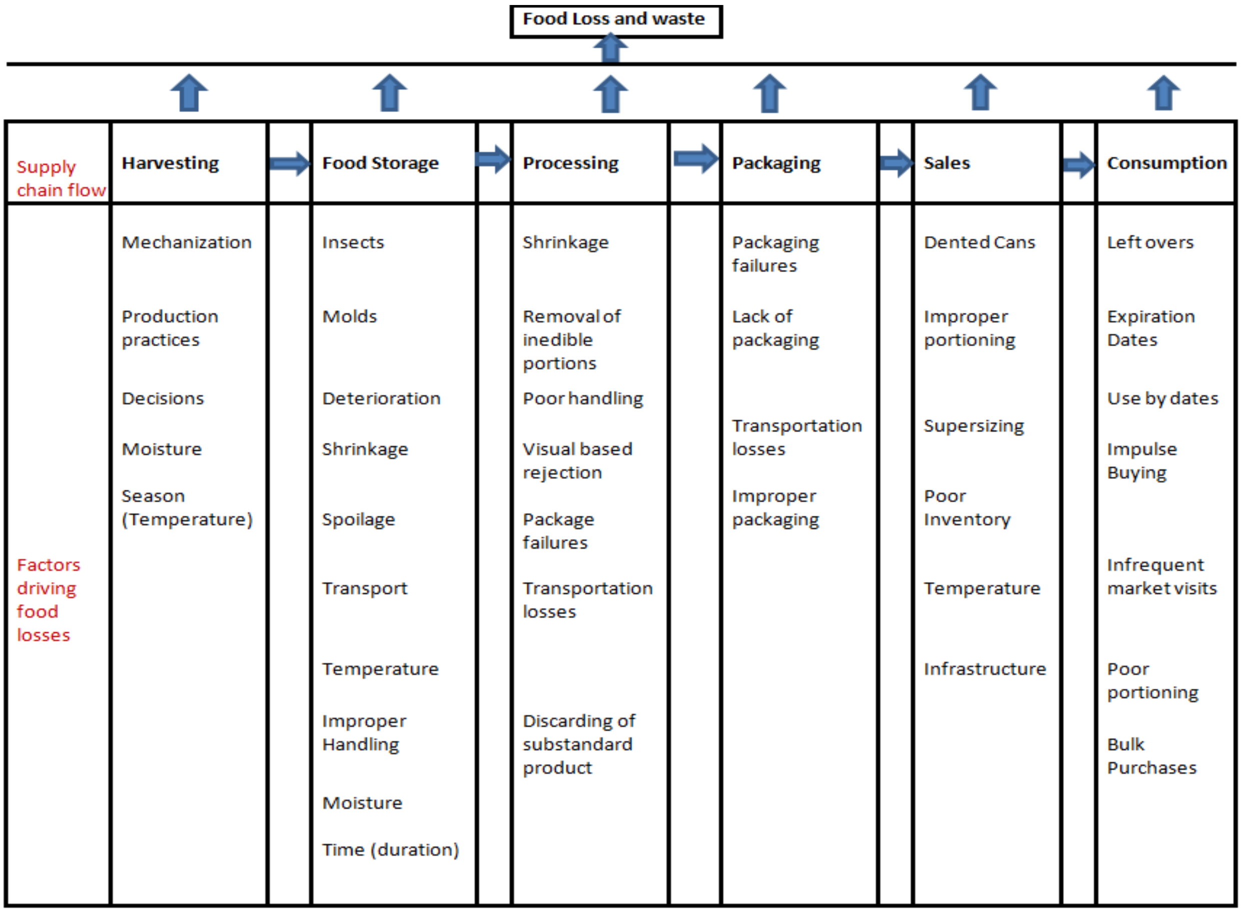
CHAPTER 2: CONCEPTUAL FRAMEWORK – POSTHARVEST LOSSES

This study uses postharvest losses as its conceptual framework and follows the processes and stages of food losses and wastes from Affognon et al. (2015) and Aulakh et al. (2013). Some stages were combined to best match the loss scenarios presented by Gustavsson et al. (2011) and data available in FAOSTAT (2013).

Postharvest losses were defined by Grolleaud, (2002) as "a measurable reduction in foodstuffs which affect quantity and or quality" when removed from the supply chain. Post-harvest losses play an important role in increasing world food prices, thereby depriving food access to poor people around the world, but relatively more so in less developed countries where more than 50% of household income is spent on food (FAO, 2008; Lam, 2011). Quality losses occur because of incidences of birds, mites, rodents, insect, and other pests and by contamination by mycotoxins and pesticide residues, poor handling of food due to inefficient storage facilities, transportation and packaging can lead to physical and chemical changes in fat, carbohydrates, protein and physical appearances (Aulakh et al., 2013). When this qualitative deterioration makes food unfit for human consumption, it contributes to food loss by decreasing its nutritional value, rendering it unsafe for healthy food consumption, and resulting in economic losses through missed market opportunities and losing attributes that are appealing to consumers (Hodges et al., 2011; Kader, 2004). These losses and wastes threaten food security, nutrition, and financial security for many poor and low income people (World Bank, 2011).

At a 2012 convention in Nairobi, Kenya, a team of African and international postharvest researchers developed a conceptual framework that considers the postharvest system (Affognon et al., 2015) and concluded that losses occur at seven different steps, including "(i) at harvest; (ii) during preliminary processing; (iii) at handling; (iv) during transportation and distribution; (v) at storage due to pests, spillage, spoilage, and contaminations; (vi) during processing due to inefficient technologies; and finally (vii) during commercialization." The framework presents food losses and food wastes by activities and practices from farm-to-fork, (resulting from premature harvesting, and lack of advanced storage and processing facilities and infrastructure) and recognizes such losses and wastes in terms of both quantity and quality (Affognon et al., 2015).

The food losses are due to different factors that cause food wastes and at each stage, and most of the known factors are shown in Figure 1. The relative contribution of each stage or factor to total losses and wastes varies across countries/regions and commodities. For instance, developed countries incur most of their losses at the retail and consumer levels, while less developed countries lose most of their food at much earlier stages (Parfitt et al., 2010; Gustavsson et al., 2011; Munesue et al., 2015). Therefore, estimating losses for each region requires considering different factors that vary across countries and regions and food types. Estimating losses for a well-integrated supply chain requires accounting for a small number of factors compared to a supply chain that allows food to undergo many transactions before they reach the final consumer (Aulakh et al., 2013).



Source: Aulakh, J., & Regmi, A. (2013). Post-harvest food losses estimation-development of consistent methodology.

Figure 1. Processes in the food supply chain

In this study, such losses happening before the harvest stage were not considered, because the data used in this study did not have pre-harvest losses represented or a category from which they could be derived from. Figures 2 and 3 depict steps that were followed to estimate food losses and wastes for each crop/food type in each country, at each stage of the food supply chain.

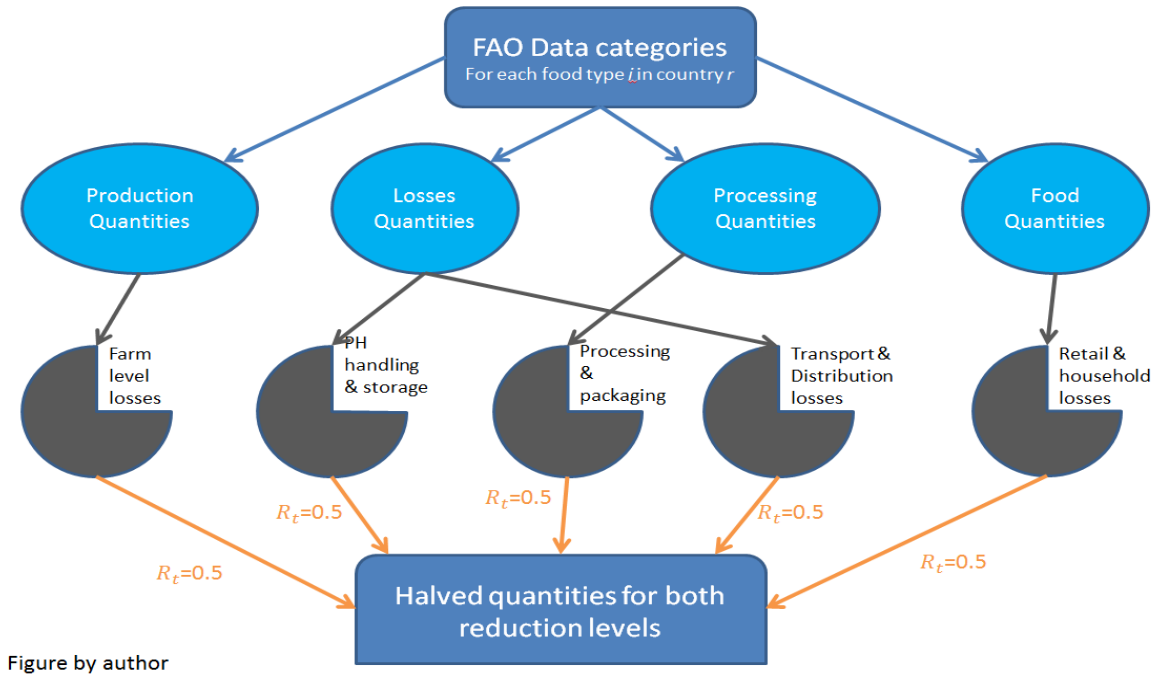


Figure 2. Steps for estimating food losses and wastes

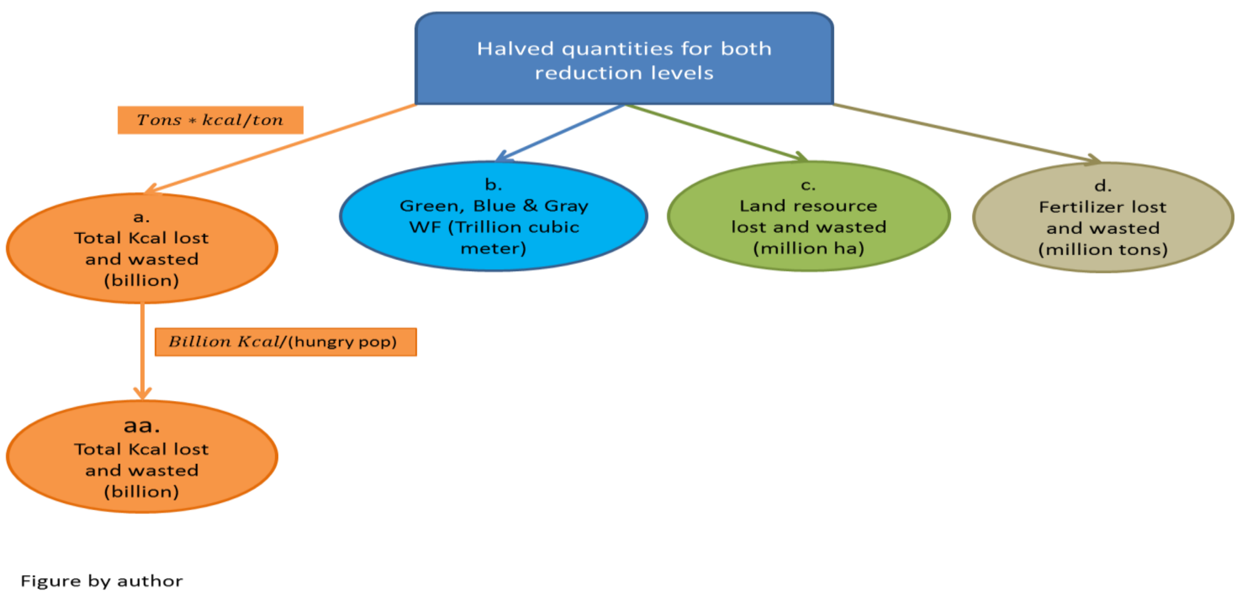


Figure 3. Steps for estimating calories and resources

CHAPTER 3. METHODS AND PROCEDURES

3.1. Country, regional and crop coverage

This study used data from the Food and Agricultural Organization (FAOSTAT, 2013). The data covered 172 countries, which were then aggregated and presented by “regions” as defined by Gustavsson et al. (2011, 2013), leading to seven regional aggregations plus two aggregates that allow for analyzing the data as developed versus less developed countries, as defined by World Economic Situation and Prospects (Outlook, 2014). This led to 38 developed countries (shown in Table 2) and 134 developed countries (shown in Figure 4). In Figure 4, the country coverage is expanded to include specific countries based on the data available in FAO (FAOSTAT, 2013).

Table 2 List of 38 developed countries

European Countries		**Non-European countries**
Austria	Latvia	Australia
Belgium	Lithuania	Canada
Bulgaria	Luxembourg	Israel
Croatia	Malta	Japan
Cyprus	Netherlands	New Zealand
Czech Republic	Norway	South Korea
Denmark	Poland	United States of America
Estonia	Portugal	
Finland	Romania	
France	Slovakia	
Germany	Slovenia	
Greece	Spain	
Hungary	Sweden	
Iceland	Switzerland	
Ireland	United Kingdom	
Italy		

SSA

Angola
Benin
Botswana
Burkina Faso
Cabo Verde
Cameroon
Central African Republic
Chad
Congo Republic of
Cote d'Ivoire
Djibouti
Ethiopia
Gabon
Gambia
Ghana
Guinea
Guinea-Bissau
Kenya
Lesotho
Liberia
Madagascar
Malawi
Mali
Mauritania
Mauritius
Mozambique
Namibia
Niger
Nigeria
Rwanda
Sao Tome and Principe
Senegal
Sierra Leone
South Africa
Sudan
Swaziland
Tanzania
Togo
Uganda
Zambia
Zimbabwe

SSEA

Afghanistan
Bangladesh
Brunei Darussalam
Cambodia
China
India
Indonesia
Japan[1]
Lao People's Dem. Rep
Malaysia
Maldives
Mongolia
Myanmar
Nepal
North Korea
Oman
Pakistan
Philippines
Sri Lanka
Thailand
Timor-Leste
Viet Nam

NAWCA

Algeria
Azerbaijan
Egypt
Georgia
Iran
Iraq
Israel[1]
Jordan
Kazakhstan
Kuwait
Kyrgyzstan
Lebanon
Morocco
Saudi Arabia
Tajikistan
Tunisia
Turkey
Turkmenistan
Yemen
United Arab Emirates
Uzbekistan

LAC

Argentina
Belize
Bolivia
Brazil
Chile
Colombia
Costa Rica
Cuba
Dominica
Dominican Republic
Ecuador
El Salvador
Guatemala
Guyana
Honduras
Nicaragua
Paraguay
Peru
Suriname
Trinidad & Tobago
Uruguay
Venezuela

IA

China
India
Indonesia
Malaysia
Philippines
Republic of Korea[1]
Thailand

NAO

Antigua and Barbuda
Australia[1]
Bahamas
Barbados
Bermuda
Canada[1]
Fiji
French Polynesia
Grenada
Haiti
Jamaica
Kiribati
Mexico
New Caledonia
New Zealand[1]
Panama
Saint Kitts and Nevis
Saint Lucia
Saint Vincent and the Grenadines
Samoa
Solomon Islands
United States of America[1]
Vanuatu

Other European countries

Albania[2]
Armenia[2]
Belarus[2]
Bosnia & Herzegovina[2]
Macedonia[2]
Montenegro[2]
Republic of Moldova[2]
Russian Federation[2]
Serbia[2]
Ukraine[2]

Figure 4. List of 134 less developed countries by respective regions

[1] Countries belonging to a geographic/regional group but not classified as less-developed countries
[2] Countries belonging to European region but also classified as less developed countries herein this study

All calculations were done at the national level before being aggregated to regional levels. The regional aggregates included: Sub-Saharan Africa, Europe, Industrialized Asia, Latin America and Caribbean, North Africa West and Central Asia, North America and Oceania, South and South Eastern Asia which were abbreviated as SSA, Europe, IA, LAC, NAWCA, NAO, and SSEA respectively. Two additional regions were created: developed and less developed regions to enable the comparison of the two regions in this study. Table 3 represents the global food balance in 2013 for regions included in this study and their corresponding data on production, imports, exports, domestic supply, feed, quantities processed and packaged, and consumption. The study included 69 food types classified into different categories, as presented in Figure 5.

Table 3. The global food balance in 2013

Region/Crop	Production	Imports	Exports	Domestic Supply	Feed	Processed	Consumed
Developed Countries							
Cereals	859.5	150.5	234.9	731.9	368.1	56.3	129.7
Roots & Tubers	86.6	25.3	25.7	87.5	4.9	3.1	62.8
Oilseeds & Pulses	230.5	83.1	110.6	199.5	12.1	125.5	36.7
Fruit & vegetables	218.8	136.3	88.95	267.8	2.6	31.5	215.5
Meat	121.2	26.1	39.6	107.8	2.4	636	98
Eggs	16.1	1.6	1.9	15.9	3	0	14.1
Dairy	305.6	65.5	106.9	268.1	19.2	216	233.2
Less developed Countries							
Cereals	1,663.9	249.5	190.4	1,675.1	505.4	38.3	899.3
Roots & Tubers	753.5	46.9	41.2	757.5	170.9	14.8	403.4
Oilseeds & pulses	613	167.5	154.1	615.9	41.3	306.3	161.6
Fruits & vegetables	1,553.7	65,763	122.4	1,498.8	51	19.6	1,298.1
Meat	229.9	25.2	16.9	238.3	210	111	230.5
Eggs	57.7	922	872	57.8	70	0	50.3
Dairy	460.7	53.9	21.1	493.8	62.8	47	409.3

Data source: (FAOSTAT, 2013). Data are in millions of tons

Cereal
Barley
Corn
Millet
Oats
Other coarse grain
Rice
Rye
Sorghum
Wheat

Livestock and livestock products
Bovine meat
Edible offal
Edible animal fats
Goat meat
Pig meat
Poultry meat
Sheep meat

Roots and Tubers
Cassava
Plantains
Potatoes
Sweet potatoes
Yams
Other roots

Oil crops, oilseeds, legumes and pulses
Beans
Coconut oil
Coconuts
Cottonseeds
Cottonseed oil
Groundnuts
Groundnut oil
Maize germ oil
Nuts and their products
Oil crops
Oil crop oil
Olives
Olive oil
Palm kernels
Palm kernel oil
Palm oil
Peas
Pulses
Rape and mustard seeds
Rape and mustard oil
Rice bran oil
Sesame seeds
Sesame seed oil
Soybeans
Soybean oil
Sunflower seeds
Sunflower seed oil

Fruits and vegetables
Apples
Bananas
Citrus
Cloves
Dates
Grapes
Grapefruits
Fruits other
Lemons and limes
Onions
Oranges and mandarins
Pepper
Pimento
Pineapples
Spices
Tomatoes
Other vegetables

Dairy and dairy products
Butter
Cheese
Cream and milk

Figure 5. Agricultural commodities and their classification in the study

3.2. Data categorization and modifications

FAO data do not specify at which stage in the food supply chain the losses and wastes occur. Therefore, different categories were applied for different stages of the food chain when calculating losses and wastes in the following manner:

1. Quantities presented in FAOSTAT as production were used to calculate losses at the production/farm stage. The rates of losses at this stage for each commodity in each country/region estimated by Gustavsson et al. (2013) were applied for the above category only. The process restarts for each different category using a different rate in each country and each region. These rates are provided in the appendix A.
2. Losses represented in FAOSTAT refer only to losses during storage and transportation. Therefore, this study interpreted them as postharvest handling and storage and distribution, and these quantities were used only to calculate losses at those two stages by applying the respective rates of losses for each commodity in each region.
3. The quantities in the processing category of the FAOSTAT data were used to represent losses at the stage of processing and packaging by applying the respective rates for each commodity in each region.

4. Only the quantities of ‘food’ in FAOSTAT were assumed to be the quantities that finally reach the market, and therefore the wastes rates were applied to these quantities to reflect the consumption level wastes.

All data used in this study were collected at the country and commodity/crop type level. Where such data were not available at the country level, regional data were used. In very few cases, global averages were used to calculate water footprints.

3.3. Methods and modeling overview

Estimating lost and wasted food involved two scenarios. The first scenario is halving food losses and wastes using the current loss rates and applying a 50% reduction on the resulting quantities. The 50% reduction target has been advanced by a number of countries as a feasible target and adopted by many other countries and the United Nations’ sustainable developing goals (UN SDG, 2015; USDA, 2015). The second scenario involved 1) selecting the lowest reduction rates achieved in any one of the included countries/ regions and food types, 2) applying those rates to all regions and food types, and 3) applying a 50% reduction on the resulting quantities. This last scenario assumes that given the right motivation and circumstances, many countries may be willing to reduce their food wastes and food losses further than 50% - the current target of many nations. Both scenarios were calculated using percentages published by Gustavsson et al. (2011), which includes a global breakdown of food wastes and losses along the supply chain for different commodity/food groups in the different countries/regions. The percentages were reproduced and presented in the appendix A.

For each scenario, the following steps were used to estimate the lost and wasted food quantities, their calorie equivalent and the resources used to produce them for each food type in each country:

1. The quantities in each stage of food supply chain were multiplied by their respective loss or waste rates.
2. The resulting quantities in each scenario were multiplied by 0.5 to obtain the halved quantities. From this stage, the quantities were fixed and unchanged in the next stages. At this point, the quantities were aggregated to regional levels.
3. The estimated lost and wasted quantities were converted into calories using conversion factors obtained from Pradhan et al. (2013); IIASA/ FAO, (2012); Cassidy et al. (2013) and FAO, (2001). The conversion was accomplished at the country level and food/commodity type level (Kilo-calorie per ton of food type). After the conversion the calories were also aggregated to regional levels.
4. Calories from step 3 were divided by the estimated total number of people considered hungry or severely food insecure in each representative region (UN-FAO, 2013; USDA, 2015) and then by 365 to obtain kilocalories available per person per day. This allows for a direct estimation of the effects of such reduction on food security in each region.
5. The quantities from step 2 were used to estimate the amount of water needed to produce the lost and wasted food. The water resource was calculated using data from Mekonnen and Hoekstra, (2010; 2011). These data specify the amount of

water (green, blue and gray water footprint) usage by each food type measured in cubic meters per ton of food type. The water footprint is defined as an indicator of freshwater used directly or indirectly by consumers and producers. The green water footprint refers to the rainwater consumed and blue water footprint refers to the volume of surface and ground water consumed/ evaporated, while gray water footprint is an indicator of water required to assimilate pollution.

6. The land used to produce lost and wasted food was calculated by dividing the quantities in step 2 with yield levels provided in the FAO resource database (FAOSTAT, 2017). This is recorded as kg per hectare of each specific food type in each country. Since all aggregations were in million tons, these yield data were also transformed into tons per hectare. The data contained country yield levels from 1960 to 2014. However, in this study, data for 2013 and 2014 were used and in some instances the regional average yield levels were applied. The resulting quantities were aggregated and compared at regional levels.
7. The study also used fertilizer data from the FAO resource (FAOSTAT, 2017) to estimate the fertilizer used to produce lost and wasted food in each country. Knowing the quantities of food lost and wasted in both scenarios, yield levels per hectare, and fertilizer applications per hectare in each country allowed us to estimate the amount of fertilizers used to produce such lost and wasted food by multiplying the hectares lost with fertilizer application per hectare in each

country. The resulting quantities were then aggregated and compared at regional levels.

The water, land and fertilizer computations were not conducted through the stages of the food chain. Since they are all used at the production stage, the calculations were accomplished using total aggregated quantities of lost and wasted food from step two.

3.4. Model equations and parameters

The following equations are the arithmetic explanation of the scenarios and steps described above, and were developed and used in this study. All calculations were performed and aggregated using Microsoft Excel 2013. Estimating quantities wasted and lost in both scenarios and applying the 0.5 reduction rate in each case was the first step. All other steps depended on the quantities obtained in this initial step.

3.4.1. Equations for computing the lost and wasted food at the 50% reduction rate

Production stage: Farm/ harvesting

$$QP_{lw} = \sum_{r,k}^{i} \left(QP_{i,r,k} * R_{a_{i,r,k}}\right) * R_t \quad (1)$$

Post-harvest handling and storage:

$$Qhs_{lw} = \sum_{r,k}^{i} \left(Qhs_{i,r,k} * R_{hs_{i,r,k}}\right) * R_t \quad (2)$$

Processing and packaging:

$$Qpp_{lw} = \sum_{r,k}^{i}\left(Qpp_{i,r,k} * R_{pp_{i,r,k}}\right) * R_t \quad (3)$$

Distribution and Transportation:

$$Qd_{lw} = \sum_{r,k}^{i} \left(Qd_{i,r,k} * R_{d_{i,r,k}}\right) * R_t \tag{4}$$

Consumption:

$$Qf_{lw} = \sum_{r,k}^{i}(Qc_{i,r,k} * R_{C_{i,r,k}}) * R_t \tag{5}$$

Where Qp_{lw}, Qhs_{lw}, Qpp_{lw}, Qd_{lw}, Qf_{lw} represent the total reduction quantities in weight for food lost and wasted at the stages of farm/production, post-harvest handling and storage, processing and packaging, distribution and transportation, and consumption, respectively, after the target rate (R_t) of 0.5 has been applied.

$Qp_{i,r,k}$, $Qhs_{i,r,k}$,$Qpp_{i,r,k}$, $Qd_{i,r,k}$, $Qc_{i,r,k}$ represent the total quantities of food in weight at the stages of farm/production, post-harvest handling and storage, processing and packaging, distribution and transportation, and consumption stages respectively for commodity i, in country r at the stage k. Lastly, $R_{a_{i,r,k}}$, $R_{hs_{i,r,k}}$, $R_{pp_{i,r,k}}$, $R_{pp_{i,r,k}}$, $R_{d_{i,r,k}}$, $R_{C_{i,r,k}}$ represent the different rates used to compute the food lost or wasted at the farm/production, post-harvest handling and storage, processing and packaging, distribution and transportation, and consumption stages, respectively, for commodity i in country r at stage k obtained from the SIK report (Gustavsson et al., 2013). The previously presented rates, i.e., $R_{a_{i,r,k}}$, $R_{hs_{i,r,k}}$, $R_{pp_{i,r,k}}$,$R_{pp_{i,r,k}}$, $R_{d_{i,r,k}}$,$R_{C_{i,r,k}}$ are applicable at the stage levels of the food supply chain. However, they differ from rates applied at the commodity level of each stage. In other words, the above rates contain loss and waste ratios applied at the food type level. Thus, it can be shown that depending on what type of food type being computed, the rates comprised the different levels corresponding to that commodity i in country r at stage k. Therefore, losses and wastes rates from cereals, roots and tubers, oilseeds and pulses, fruits and vegetables, meats, milk and other dairy, respectively include:

At the production level;

$$\{rpc_{i,r}, rprt_{i,r}, rpop_{i,r}, rpfv_{i,r}, rpm_{i,r}, rpd_{i,r}\} \in R_{a_{i,r}} \tag{6}$$

At post-harvesting and storage level;

$$\{rhsc_{i,r}, rhsrt_{i,r}, rhsop_{i,r}, rhsfv_{i,r}, rhsm_{i,r}, rhsd_{i,r}\} \in R_{hs_{i,r}} \tag{7}$$

At the processing and packaging level;

$$\{rppc_{i,r}, rpprt_{i,r}, rppop_{i,r}, rppfv_{i,r}, rppm_{i,r}, rppd_{i,r}\} \in R_{pp_{i,r}} \tag{8}$$

At the distribution and transportation level;

$$\{rdc_{i,r}, rdrt_{i,r}, rdop_{i,r}, rdfv_{i,r}, rdm_{i,r}, rdd_{i,r}\} \in R_{d_{i,r}} \tag{9}$$

At the consumption level, losses and wastes from cereals;

$$\{rcc_{i,r}, rcrt_{i,r}, rcop_{i,r}, rcfv_{i,r}, rcm_{i,r}, rcd_{i,r}\} \in R_{C_{i,r}} \tag{10}$$

Estimating the lowest achieved quantities use the same formulas as in equations 1 through 5. However, the rates of losses and wastes in 6 through 10 are different from the previous scenario. The equations are omitted here to avoid repetition. From this step forward, all remaining calculations used the quantities of food lost and wasted at both scenarios to calculate the amount of calories, water, land and fertilizer that were used to produce the lost and wasted food.

3.4.2. Computing caloric equivalency of wasted and lost food

Production stage: Farm/Post-harvesting

$$Pkcal_{i,r,k} = QP_{lw} * \ Kcal_{i,r,k} = \left(\sum_{r,k}^{i} \left(QP_{i,r,k} * R_{a_{i,r,k}}\right) * R_t\right) * Kcal_{i,r,k} \quad (11)$$

Post-harvest handling and storage:

$$hskcal_{i,r,k} = Qhs_{lw} \ * \ Kcal_{i,r,k} = \left(\sum_{r,k}^{i} \left(Qhs_{i,r,k} * R_{hs_{i,r,k}}\right) * R_t\right) * \ Kcal_{i,r,k} \quad (12)$$

Processing and packaging:

$$ppKcal_{i,r,k} = Qpp_{lw} * Kcal_{i,r,k} = (\sum_{r,k}^{i}\left(Qpp_{i,r,k} * R_{pp_{i,r,k}}\right) * R_t) * \ Kcal_{i,r,k} \quad (13)$$

Distribution and Transportation:

$$dKcal_{i,r,k} = Qd_{lw} * Kcal_{i,r,k} = (\sum_{r,k}^{i}\left(Qd_{i,r,k} * R_{d_{i,r,k}}\right) * R_t) * Kcal_{i,r,k} \quad (14)$$

Consumption:

$$cKcal_{i,r,k} = Qf_{lw} * Kcal_{i,r,k} = (\sum_{r,k}^{i}(Qc_{i,r,k} * R_{c_{i,r,k}}) * R_t) * Kcal_{i,r,k} \quad (15)$$

Where $Pkcal_{i,r,k}$, $hskcal_{i,r,k}$, $ppKcal_{i,r,k}$, $dKcal_{i,r,k}$, $cKcal_{i,r,k}$ represent the total reduction quantities in kilocalories for food lost and wasted at the stages of farm/production, post-harvest handling and storage, processing and packaging, distribution and transportation, and consumption respectively. The above quantities and qualities are grouped both by regional and food type categories.

The reduction of food insecurity can be calculated by dividing the kilocalories available through waste and loss reduction by the number of food insecure people by region. The amount of kilocalories available after halving lost or wasted food were then used to determine the number of people that could be nourished in each region of interest, based on the FAO calculation and recommendation of regional minimum dietary energy requirement (MDER) as the cut-off point.

The direct calculation mentioned above is important to show the amount of food and calories that could be directly available region-wise by halving locally available food from wastage and loss. However, it cannot present the rate of reduction of food insecurity given the amounts of food available through halving losses and wastes. For this reason, the FAO methodology for estimating food insecurity (Appendix B) was used (FAO, 2008, FAO, 2014), and FAO's daily caloric requirements for all individuals served as the standard (FAO, 2017). The region of SSA lacked a lot of data needed to calculate food losses and food waste for 7 countries, (Democratic Republic of the Congo, Sudan, South Sudan, Eritrea, Somalia, Equatorial Guinea, Libya), but these were represented in the number of food insecure people in 2013. In order to minimize overestimation and underestimation, these countries were excluded in the estimation of changes in food available regionally.

3.4.3. The calculation for water footprint for each country/region by each type of food

Production stage: Farm/Post-harvesting:

$$pb_{wf} = \left(\sum_{r,k}^{i} \left(QP_{i,r,k} * R_{a_{i,r,k}}\right) * R_t\right) * B_{wf} \qquad (23\text{ i})$$

$$pg_{wf} = \left(\sum_{r,k}^{i} \left(QP_{i,r,k} * R_{a_{i,r,k}}\right) * R_t\right) * G_{wf} \qquad (23\text{ ii})$$

$$py_{wf} = \left(\sum_{r,k}^{i} \left(QP_{i,r,k} * R_{a_{i,r,k}}\right) * R_t\right) * Y_{wf} \qquad (23\text{ iii})$$

Post-harvest handling and storage:

$$hsb_{wf} = (\sum_{r,k}^{i} (Qhs_{i,r,k} * R_{hs_{i,r,k}}) * R_t) * b_{wf} \tag{24 i}$$

$$hsg_{wf} = (\sum_{r,k}^{i} (Qhs_{i,r,k} * R_{hs_{i,r,k}}) * R_t) * g_{wf} \tag{24 ii}$$

$$hsy_{lw} = (\sum_{r,k}^{i} (Qhs_{i,r,k} * R_{hs_{i,r,k}}) * R_t) * y_{wf} \tag{24 iii}$$

Processing and packaging:

$$ppb_{lw} = \left(\sum_{r,k}^{i}\left(Qpp_{i,r,k} * R_{pp_{i,r,k}}\right) * R_t\right) * b_{wf} \tag{25 i}$$

$$ppg_{lw} = \left(\sum_{r,k}^{i}\left(Qpp_{i,r,k} * R_{pp_{i,r,k}}\right) * R_t\right) * g_{wf} \tag{25 ii}$$

$$ppy_{lw} = \left(\sum_{r,k}^{i}\left(Qpp_{i,r,k} * R_{pp_{i,r,k}}\right) * R_t\right) * y_{wf} \tag{25 iii}$$

Distribution and Transportation:

$$db_{wf} = \left(\sum_{r,k}^{i}\left(Qd_{i,r,k} * R_{d_{i,r,k}}\right) * R_t\right) * b_{wf} \tag{26 i}$$

$$dg_{wf} = \left(\sum_{r,k}^{i}\left(Qd_{i,r,k} * R_{d_{i,r,k}}\right) * R_t\right) * g_{wf} \tag{26 ii}$$

$$dy_{wf} = \left(\sum_{r,k}^{i}\left(Qd_{i,r,k} * R_{d_{i,r,k}}\right) * R_t\right) * y_{wf} \tag{26 iii}$$

Consumption:

$$fb_{wf} = \left(\sum_{r,k}^{i}(Qc_{i,r,k} * R_{C_{i,r,k}}) * R_t\right) * b_{wf} \tag{27 i}$$

$$fg_{wf} = \left(\sum_{r,k}^{i}(Qc_{i,r,k} * R_{C_{i,r,k}}) * R_t\right) * g_{wf} \tag{27 ii}$$

$$fy_{wf} = \left(\sum_{r,k}^{i}(Qc_{i,r,k} * R_{C_{i,r,k}}) * R_t\right) * y_{wf} \tag{27 iii}$$

where b_{wf}, g_{wf} and y_{wf} represent blue, green and gray water footprint per ton of food type. pb_{wf}, pg_{wf}, and py_{wf} represent blue, green and gray water footprints from the lost food at the production stage. hsb_{wf}, hsg_{wf}, and hsy_{wf} represent blue, green and gray water footprints from the lost food at the post harvesting and storage stage. ppb_{wf}, ppg_{wf}, and ppy_{wf} represent blue, green and gray water footprints from the lost food at the processing and packaging stage. db_{wf}, dg_{wf}, and dy_{wf}represent blue, green and gray water footprints from the lost food at the distribution and transportation stage. fb_{wf}, fg_{wf}, and fy_{wf} represent blue, green and gray water footprints from the lost food at the consumption stage.

These calculations were accomplished at the food type level such as beans, peas, banana, and cassava roots. They are then aggregated to food groups/categories, namely cereal, roots and tubers, fruits and vegetables, oil crops and pulses, meats and dairy products, and finally, aggregated at the regional and country levels.

3.4.4. Calculation of land and fertilizer resources

$$Qland_{i,r} = \left(\sum_{r}^{i} \left(Q_{l\,\&\,w_{i,r}}\right) / yth_{i,r}\right) \tag{28}$$

$$Qfert_{i,r} = \left(\sum_{r,k}^{i} \left(Qland_{i,r}\right) * fert_{r}\right) \tag{29}$$

where $Qland_{i,r}$ and $Qfert_{i,r}$ represent quantities of land (million hectares) and fertilizers (million tons) used to produce lost and wasted food for commodity i in country r. $Q_{l\,\&\,w_{i,r}}$ and $yth_{i,r}$ represent total quantities of lost and wasted food and yield level (metric tons per hectare) for commodity i in country r, while $fert_r$ represents fertilizer applications (tons per hectare) in country r.

CHAPTER 4: RESULTS AND DISCUSSION

The results in this chapter are organized and discussed in the same order as the calculations in the previous chapter, starting with halving the food quantities lost and wasted in both scenarios and presented in three sections.

The first section (4.1.1) splits the presentation of losses and wastes into a) how they differ among the seven regions of focus (Sub-Saharan Africa, Europe, Industrialized Asia, Latin America and Caribbean, North Africa West and Central Asia, North America and Oceania, South and South Eastern Asia (SSA, Europe, IA, LAC, NAWCA, NAO, and SSEA, respectively), b) how they differ by less developed and developed regions, and c) the per person quantities that could be available by reducing food losses and wastes. All cases are presented first using the halved losses and wastes scenario of the current rates, and then by the lowest achieved rate scenario.

The second section (4.1.2) focuses on the nutritional equivalency in terms of kilocalories from the losses and wastes presented in the first section and are described in the same manner as the first.

The third section presents and discusses the resources used to produce the lost or wasted food. This section begins with the water footprint (WF) in section 4.1.3 in billions of cubic meters, and then covers the amount of land in million hectares (section 4.1.4) and fertilizers in million tons (section 4.1.5). All three cases (i.e., WF, land, fertilizer) are presented in the form of comparison between the seven regions and then less developed versus developed regions.

Because the data used in this study do not have the numbers of food insecure people in IA, the region of IA is presented only in cases that do not require the use of food insecure number/population for their analysis. The cases that represent IA include quantities lost and wasted by region and quantities of land and fertilizer resulting from the lost and wasted food. Therefore, when the analysis presents the available quantities and calories per person per day, the countries in IA region are represented in the SSEA since they all belong to this geographical area.

Table 4 represents the aggregated quantities of food lost and wasted by food/commodity groups at each stage of the food supply chain after applying loss and waste rates provided by Gustavsson et al. (2013) and then by the 50% reduction level. The quantities are in million tons and are used to calculate the calories lost and wasted and the resources used to produce the lost and wasted food. These results show that, quantitatively, developed regions lost more food than they wasted, which is similar to less developed regions. The difference however, is that in less developed regions, the levels are very high at all levels and stages relative to developed regions. This difference comes from the fact that percentage-wise, developed regions lose less food in the early stages and waste more food at the final stage.

Table 4. Amounts (million tons) corresponding to halved lost and wasted food by stages of the food supply chain

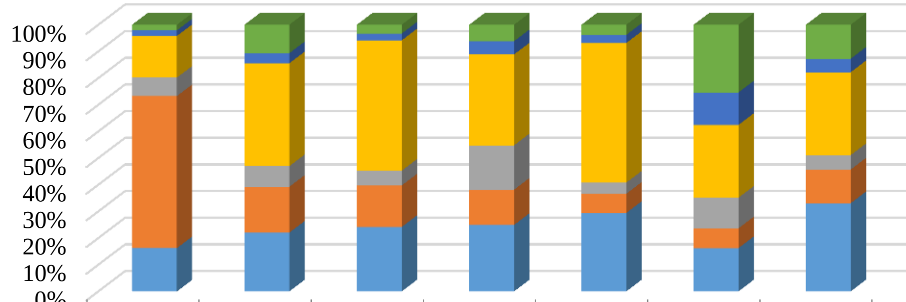
Stages of FSC / Commodity Group	Production	Post-Harvest handling and storage	Processing and Packaging	Distribution	Consumption	50% losses and wastes
Developed Countries						
Cereals	8.58	2.60	0.000	1.39	14. 49	27.07
Roots & Tubers	8.66	1.69	0.044	1.26	12.9	24.50
Oilseeds & Pulses	13.07	0.24	0.017	1,12	1.3	15.78
Fruits & vegetables	21.16	2.83	0.003	5,86	22.3	52.19
Meats	12.21	0.28	0.016	0.17	10.04	22.46
Dairy	23.96	0.61	0.001	0.61	11.6	36.81
Total	**87.64**	**7.995**	**0.042**	**10.4**	**72.7**	**178.81**
Less Developed Countries						
Cereals	28.04	72.44	0.002	26.14	133.86	260.49
Roots & Tubers	60.70	26.04	0.002	13.85	27.78	128.38
Oilseeds & pulses	21.94	10.64	0.044	4.47	4.78	41.88
Fruits & vegetables	96.10	59.39	0.010	70.27	181.94	407.72
Meats	5.21	0.078	0.001	0.37	8.54	14.19
Dairy	8.42	4.63	0.000	4.37	18.04	35.47
Total	**220.41**	**173.24**	**0.059**	**119.47**	**374.94**	**888.11**

Data are in million tons

In quantitative terms, this would mean that developed regions need to focus on reducing food losses at the production stage as they are giving to the final consumption. However, in terms of percentages, the final consumption poses a serious concern and should take precedent. In less developed regions, the opposite is almost true because the share/percent of food lost before the final stage is significantly higher than the share of food wasted at the final stage. However, in quantitative terms, the final stage still has a significant amount of food being wasted followed by production, and handling and storage stages. However, the large amount at the consumption stage may be because of the sheer size of this region as defined in this study and not because of too much waste. This means that the stages of production, postharvest handling and storage, and distribution respectively should be the focus in this region.

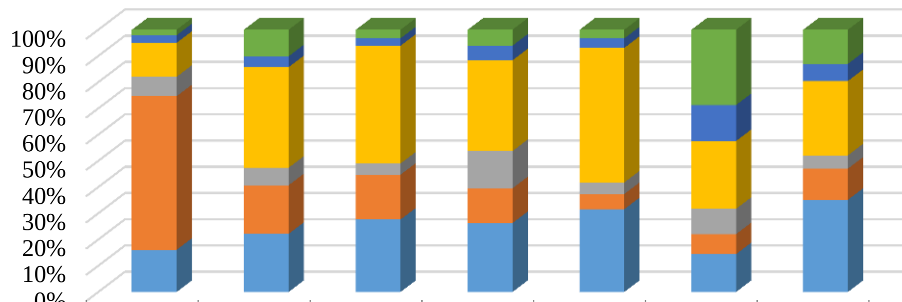
4.1. Results for food losses and wastes reduction in quantities

Figures 6 and 7 present the amount of food lost and wasted in different regions of the world and by different food types. The results indicate that at both reduction levels, North America and Oceania lost and wasted the most in dairy products, followed by Europe. In fact, NAO alone wasted more dairy than the combined losses and wastes from the remaining regions not including Europe. The same two regions lost and wasted more meat than the remaining regions in the same manner.



	SSA	Europe	IA	LAC	NAWCA	NAO	SSEA
Dairy (tons)	1.38	13.55	10.61	3.66	1.76	29.40	4.67
Meat (tons)	1.40	4.84	8.24	2.96	1.42	14.11	1.85
Fruit & vegetables (tons)	10.37	49.08	157.97	20.26	24.33	31.63	11.39
Oilseeds & Pulses (tons)	4.60	9.85	17.98	9.91	1.94	13.30	1.98
Roots & Tubers (tons)	37.91	21.86	50.23	7.86	3.34	8.60	4.62
Cereals (Tons)	10.79	28.04	78.12	14.82	13.67	18.81	12.12

Figure 6. Amounts (million tons) resulting from halving lost and wasted food through its supply chain by food type in each region

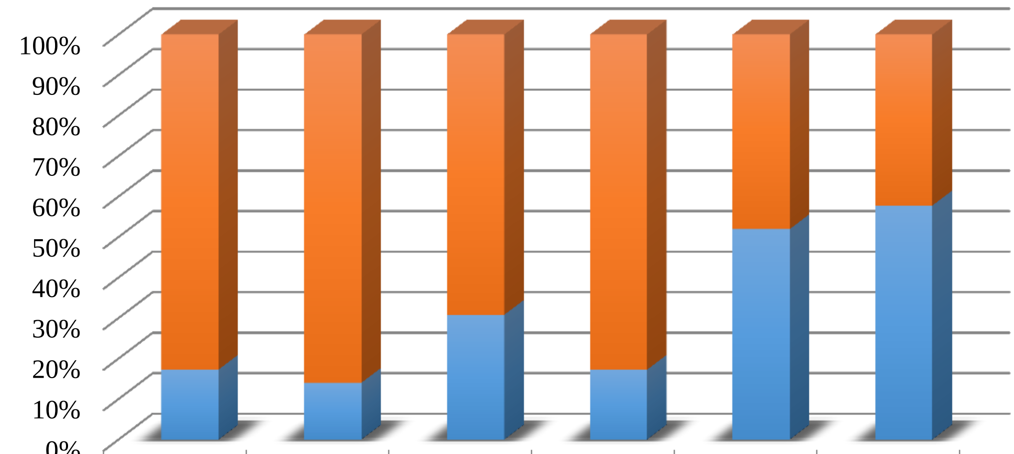


	SSA	Europe	IA	LAC	NAWCA	NAO	SSEA
Dairy (tons)	1.75	19.24	14.68	4.81	2.14	55.54	6.06
Meat (tons)	2.38	7.89	12.72	4.42	2.34	26.51	3.04
Fruit & vegetables (Tons)	10.74	72.94	202.02	27.39	33.26	50.00	13.20
Oilseeds & Pulses (Tons)	6.14	12.68	19.24	11.23	2.87	18.67	2.37
Roots & Tubers (tons)	48.53	35.24	76.99	10.49	3.74	14.75	5.54
Cereals (Tons)	13.33	42.12	124.32	20.79	20.46	27.90	16.35

Figure 7. Amounts (million tons) corresponding to the lowest achieved reduction rates in lost and wasted food through the supply chain by food type in each region

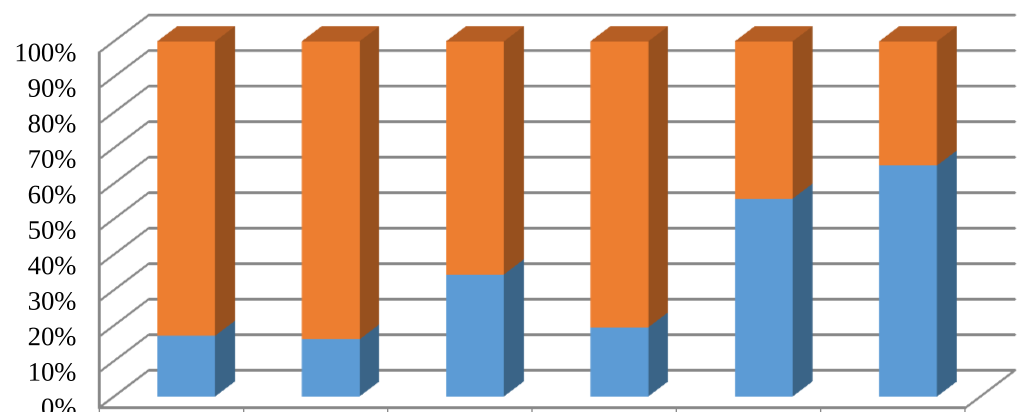
As expected, Figure 7 shows that reducing losses and wastes at the lowest achieved rates made the above numbers larger. The numbers for lost and wasted meat were very high as well and the same two regions dominated in losing and wasting more meat. However, when it comes to fruits and vegetables, cereals and oilseeds, Industrialized Asia lost more than any other region almost at the same level of NAO in dairy losses and wastes. Industrialized Asia was followed by Europe and then North America and Oceania. Industrialized Asia lost and wasted more roots and tubers than other regions, followed by Sub-Saharan Africa and Europe. This remained true for both reduction levels in all regions.

The results also reveal that less developed regions lost and/or wasted more cereals, roots and tubers, oilseeds, and fruits and vegetables than developed regions (Figures 8 and 9). This is a relatively unique result as Xue et al. (2017) reported that less developed regions are less covered and are rarely the main focus of many studies on this topic. However, developed regions lost and wasted more in dairy and meat. Although the difference in losses and wastes of dairy and meat between the two regions is not large, this was expected to be the case given that developed regions have higher production capabilities than developing regions and higher incomes in developed regions has been positively associated with more wastes (Herath and Felfel, 2016; Koivupuro et al. 2012; Lyndhurst, 2007).



	Cereal	Roots and tubers	Oilseeds	Fruits & vegetables	Meat	Milk/Dairy
LESS-DECO (Tons)	145.90	115.59	41.26	252.48	17.38	26.46
DECO (Tons)	30.48	18.85	18.37	52.55	18.80	36.21

Figure 8. Comparison of quantities (million tons) lost or wasted between developed and less developed countries at the 50% reduction rate



	Cereal	Roots and tubers	Oilseeds	Fruits & vegetables	Meat	Milk/Dairy
LESS-DECO (Tons)	219.93	163.90	48.06	329.80	27.27	35.66
DECO (Tons)	45.34	31.37	25.14	79.75	34.26	66.34

Figure 9. Comparison of quantities (million tons) lost or wasted between developed and less developed countries at the lowest achieved reduction rate

Figure 10 presents the per person quantities that could be available to food insecure people in their regions from reducing their own food losses and wastes. Figures 10 and 11 represent reductions using the currently known rate scenario and the lowest rate scenario, respectively. The results show that Europe could provide about 4.89 tons of food stuff per each person considered food insecure or hungry today in the region. This is also the region that is losing more on a per person level. For other regions, the numbers are 1.54, 0.96, 2.49, 0.73 and 0.40 tons per person for Latin America and Caribbean, North Africa West and Central Asia, North America and Oceania, South and South East Asia and Sub-Saharan Africa, respectively. When this analysis is done by developed versus less developed countries, the results show that developed region would save 2.48 tons per person per year while less developed regions would save only 0.80 tons per person per year. As the analysis goes from the current loss rates (Figure 10) to the lowest achieved rates scenario (Figure 11), the results indicate that almost all regions could increase their food savings with the exception of Sub-Saharan Africa.

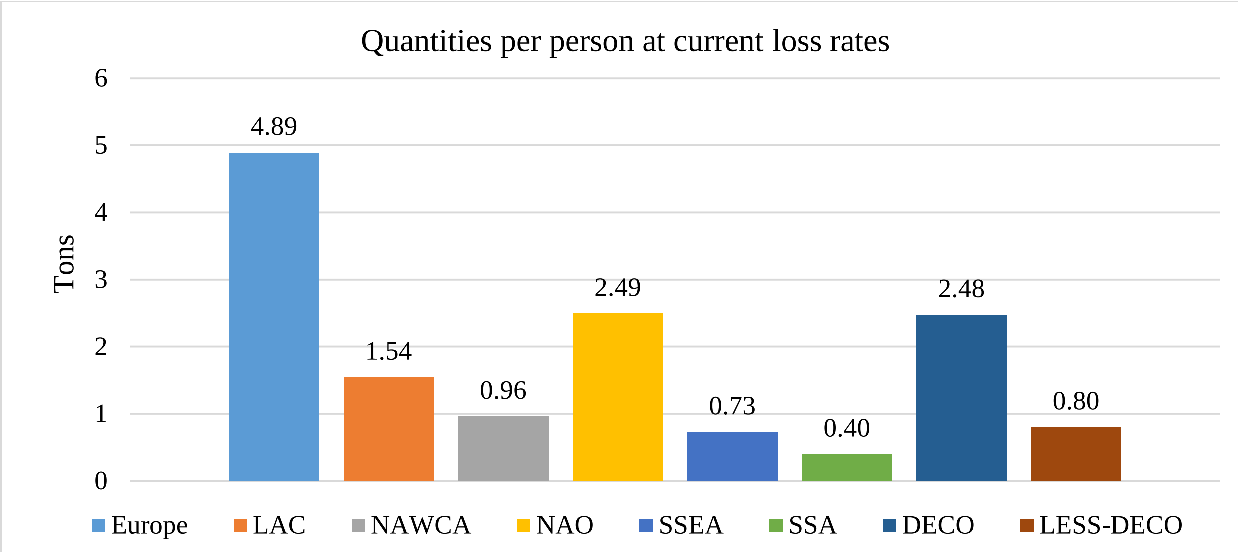


Figure 10. Available quantities per person at the current loss rates in each region

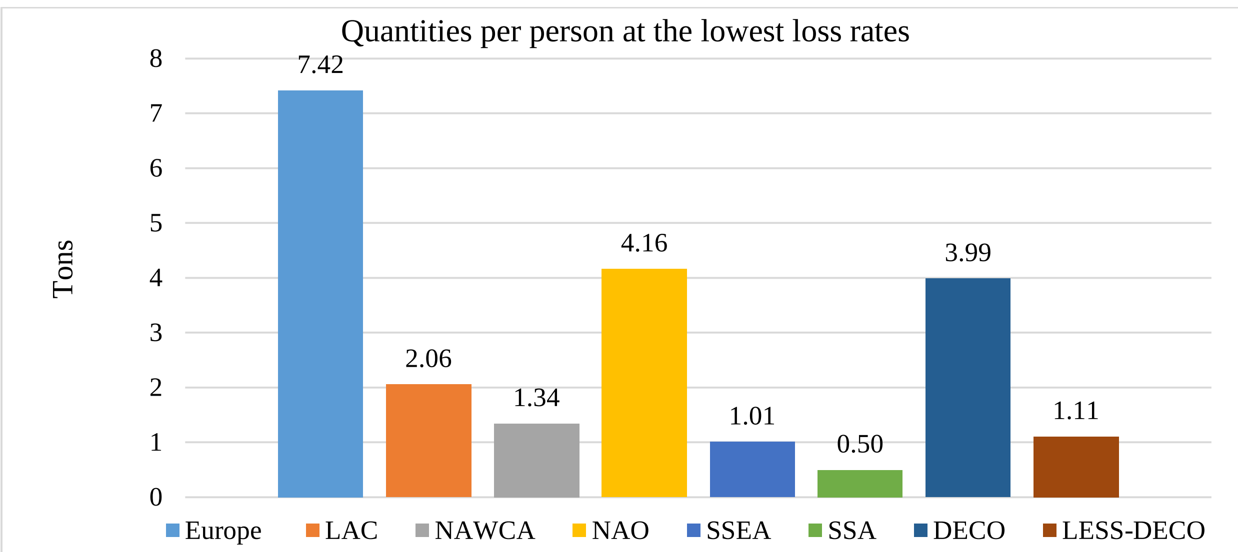


Figure 11. Available quantities per person at the lowest loss rates in each region

Reducing food losses and wastes at the lowest rates achieved by any region would provide approximately 7.42, 2.06, 1.34, 4.16, 1.01, 0.50 tons per person per year of food in Europe, LAC, NAWCA, NAO, SSEA and SSA, respectively (Figure 11). A comparison of Figures 10 and 11 indicates that the regions whose losses and wastes are low do not increase their savings much since their rates are at their lowest already. In addition, Figures 12a and 12b present reduced quantities on per person level and food type. The results indicate that for all regions more food savings would come from fruits and vegetables first and cereals second. For Europe, roots and tubers would rank third as an area of focus while dairy would rank fourth for Europe and third for NAO. Overall, halving food losses and wastes at the current rates (Figure 12a) would provide 2.93, 1.67 and 1.29 tons of fruits and vegetables, cereals and roots and tubers, respectively, for Europe. No other region is able to save enough of any food group to provide more than a ton per person at the current loss rates, though this would change to 4.37, 2.51 and 2.08 tons at the lowest achieved reduction rates (Figure 12b) for the same food types and region.

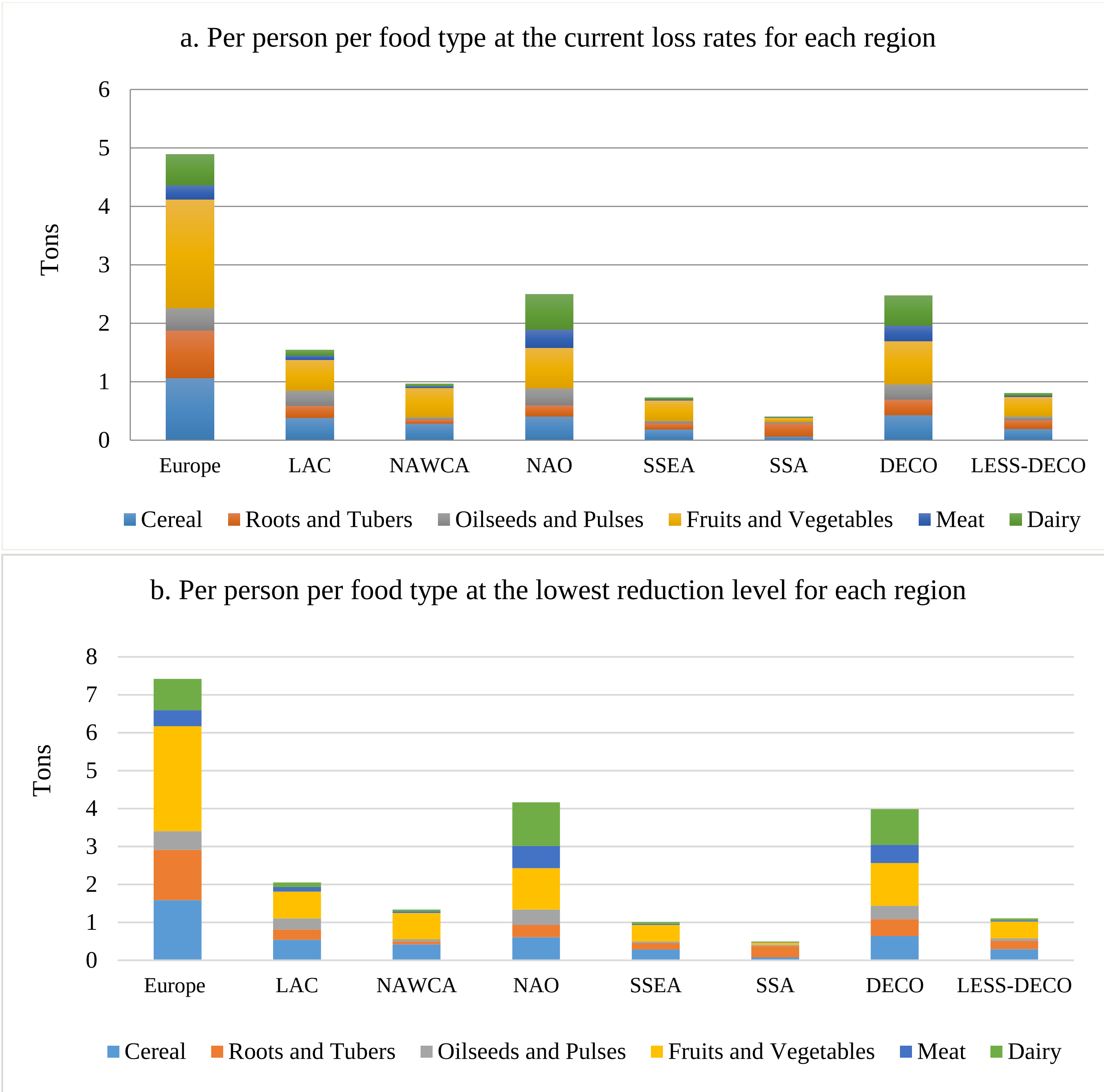


Figure 12. Total available quantities per person per day per food type in each region a) current loss rate and b) the lowest achieved reduction levels

4.2. Results for food losses and wastes reduction in calories

Figures 13 and 14 present the amount of calories that would be available to consumers if both scenarios of food loss and food wastes reduction levels were achieved. It is not surprising that the pattern is the same as in Figures 10 and 11. Europe and NAO had the highest quantities of calories available per person of approximately 24.12 and 19.88 thousand kcals per day, respectively, at the current loss rates. At the lowest achieved reduction level, the above quantities would change to 33.58 and 33.68 thousand kcals per person per day, respectively. Every region would save enough calories to feed all food insecure people in their region in both scenarios, with the exception of SSA, which would save approximately 1832 kcals per person per day at the current loss rates (Figure 13a), but would be able to feed all of its food insecure people 2341 kcals per person per day at the lowest loss rates achieved (Figure 13b). Also not surprising, SSA and SSEA have the smallest quantities available to consumers given the number of people considered food insecure in these two regions. At the current loss rates, LAC, NAWCA, SSEA, less developed regions and developed regions would save 10.04, 4.44, 3.45, 3.95 and 17.67 thousand kcal per person per day for every food insecure person in 2013. These numbers would change to 13.03, 6.42, 4.89, 5.52, and 28.81 thousand kcals per person per day at the lowest loss rates.

Analyzing this from the developed versus less developed country context, people in these two regions would have access to enough calories at both loss reduction levels with no need to increase food production or even import anything from other regions.

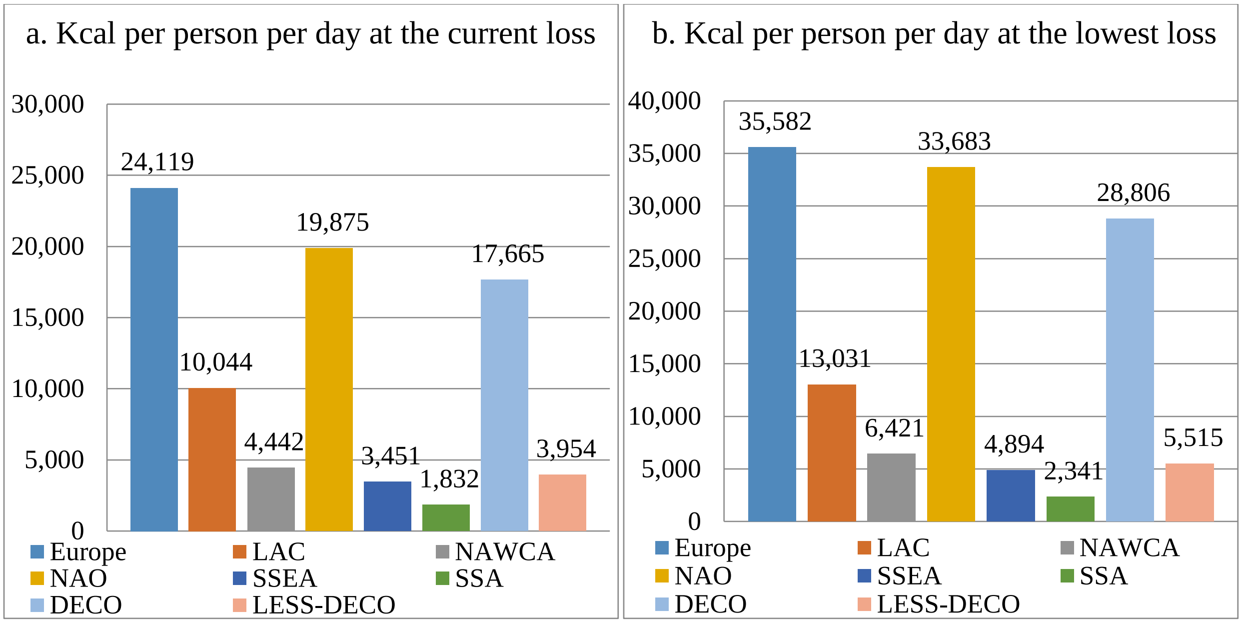


Figure 13. Available quantities per person per day in each region at a) current loss rate and b) the lowest achieved reduction levels

The above estimates provide a means to focus on crops that would be the source of food savings through a relative comparison among regions and food types. Figures 14 a and b indicate that at both reduction scenarios, efforts to reduce lost and wasted food should be based on specific regional characteristics and food types to ensure efficiency. Europe should focus on cereals, dairy, and oilseeds and pulses as the three main areas for waste reduction that would provide more calorie savings, while NAO would have to begin its efforts on dairy and then cereals, oilseeds and pulses and meats. Overall, cereals were the dominant food type in all regions, showing their importance in feeding the world popualtions, but also their effects when they are lost or wasted.

The analysis on effects on food security using the FAO methodology (FAO, 2008), showed that applying the current loss rates to the lowest loss rates, SSA would save enough calories to feed approximately 145 to 185 million people representing 87 % to more than 100% of their food insecure populations in 2013, excluding the populations of countries that were not represented in the data. It is the only region that would not be able to feed all of its food insecure people at the current reduction rates. Conversely, calories lost and wasted in Europe, NAO, LAC, and NAWCA, would feed 2100 kcals per person per day to approximately 313, 426, 184, and 102 million people at the current loss rates and approximately 490, 720, 238, and 147 million people at the lowest loss rates. Overall, the results show that halving lost and wasted food at the current loss rates could make available calories to feed over 1.98 billion people and approximately 2.93 billion people when analyzed at the lowest loss rates.

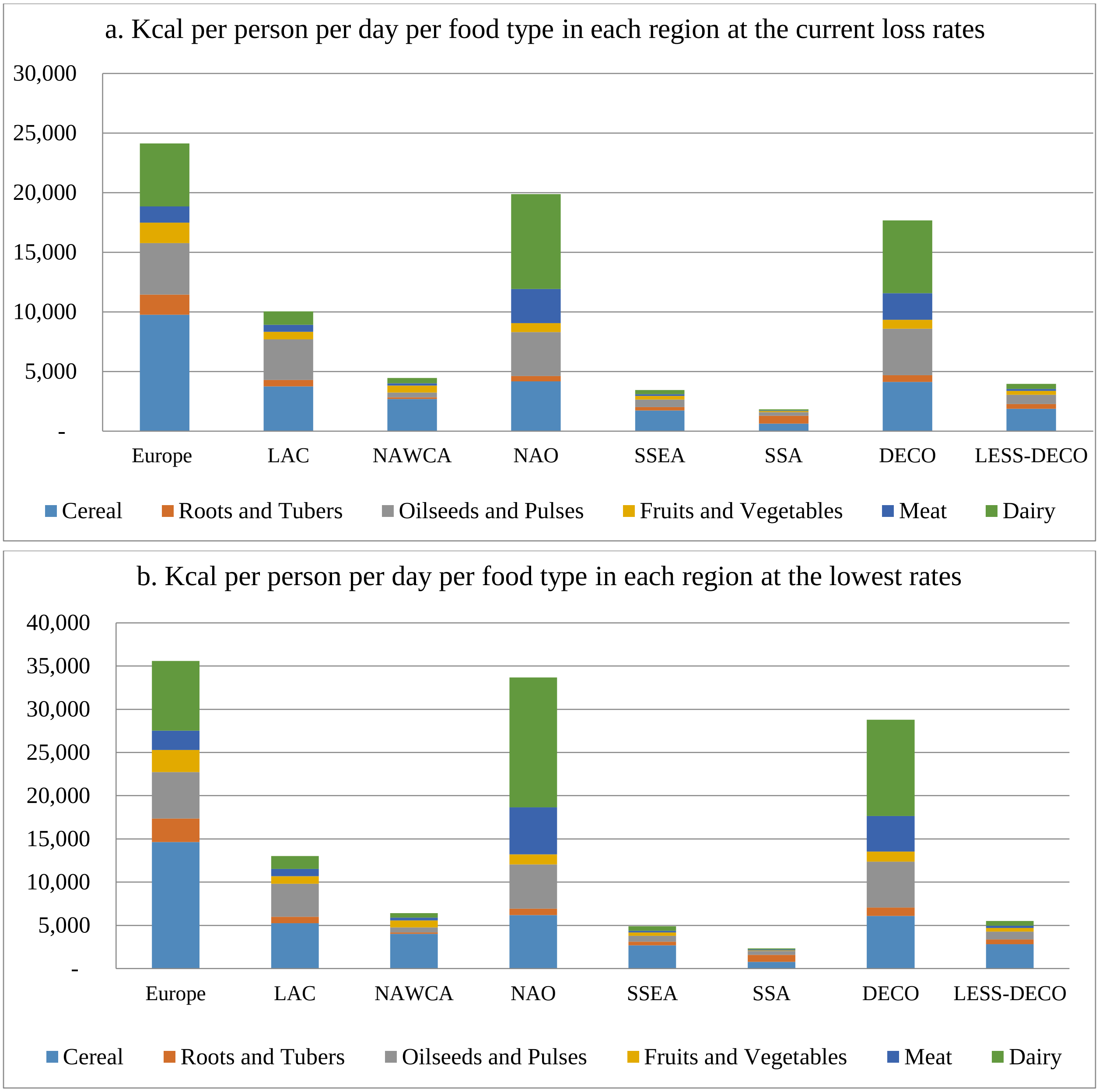


Figure 14. Calories from food that could be available per person in each region a) current loss rate and b) the lowest achieved reduction levels

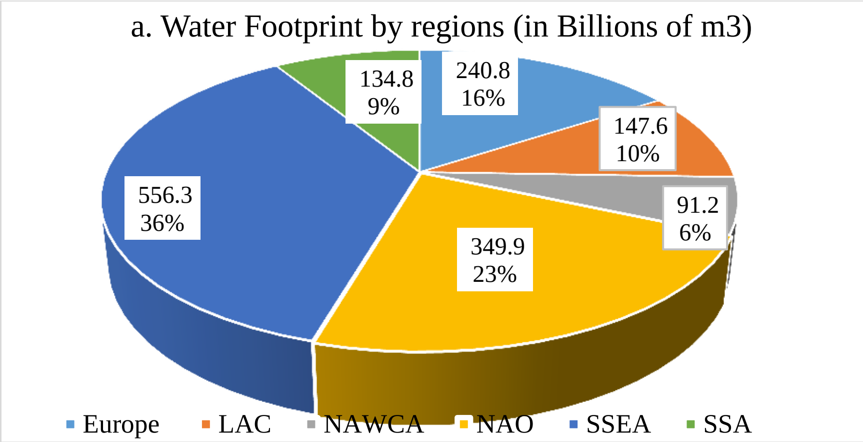
4.3. Water resources used for producing wasted and lost food in both scenarios

The results indicated that reducing food lost and wasted in 2013 by 50% would save approximately 1,520 billion cubic meters (m^3) of water, of which 36%, 23%, 16%, 10%, 6% and 9% would be saved from SSEA, NAO, Europe, LAC, NAWCA and SSA, respectively (Figure 15a). This amount consisted of 470.365 billion m^3 from developed regions and 1,050 billion m^3 from less developed regions (Appendix Tables A-9 and A-11). In terms of food type, the total water footprint accounted for 366.7 billion m^3 for cereals, equivalent to 24% of the total global water footprint from lost and wasted food at the 50% reduction level. Cereals were followed by 296.9 billion m^3 from dairy and dairy products accounting for 20%, while meats, fruits and vegetables, oilseeds and pulses and roots and tubers followed each other with 275.3, 207.9, 200.2, and 173.4 billion m^3 (acounting for 18%, 14%, 13% and 11%, respectively, of the total water footprint (Figure 15b)). Furthermore, the green, blue, and gray water footprint accounted for 80.2%, 9.5% and 9.3% of the total water footprint, respectively, (Appendix Tables A-9 and A-11).

The water footprint of food lost and wasted at the lowest achieved level (Figure 16) indicated the same pattern, but with higher quantities of water footprint. In this case, the results indicated that reducing food lost and wasted in 2013 at the lowest rate achieved would save approximately 2,230 billion cubic meters (m^3), of which 36%, 28%, 16%, 8%, 7% and 5% would be saved from SSEA, NAO, Europe, LAC, SSA and NAWCA respectively (Figure 16a). This amount consisted of 805.833 billion m^3 from developed regions and 1,424 billion m^3 from less developed regions (Appendix Tables A-10 and A-12). With respect to food types, the highest loss came from cereals which alone comprised of 544.97 billion m^3, accounting for 24% of the global water footprint from food loss and waste, followed by dairy products at 483.7 billion m^3 (22%). Meats, fruits and vegetables, oilseeds and pulses and roots and tubers followed at 472.1 billion m^3, 259.5 billion m^3, and 238.8 billion m^3, 231.2 billion m^3, respectively, accounting for 21%, 12%, 11% and 10%, respectively, (Figure 16b).

At the aggregate, all regions in this study wasted and lost more green water than blue and gray water combined, but such losses and wastes are much greater in less developed regions. The green water footprint accounted for a larger portion. Of the 1520 billion m^3, 1233 billion m^3 came from green water footprint alone and 386 and 847 billion m^3 were from developed and less developed regions, respectively (Figure 17). This amount would consist of 805.8 billion m^3 from developed regions and 1,424.5 billion m^3 from less developed regions (Appendix Tables A-10 and A-12) and approximately 80.4%, 10.1% and 9.5% would be from the green, blue, and gray total water footprint, respectively (Appendix Tables A-10 and Table A-12).

Again, the green water footprint accounted for the largest share. Of the 2,230 billion m^3, 1794 billion m^3 came from the green water footprint alone, and 663 and 1,131 billion m^3 were from developed and less developed regions, respectively (Figure 18).



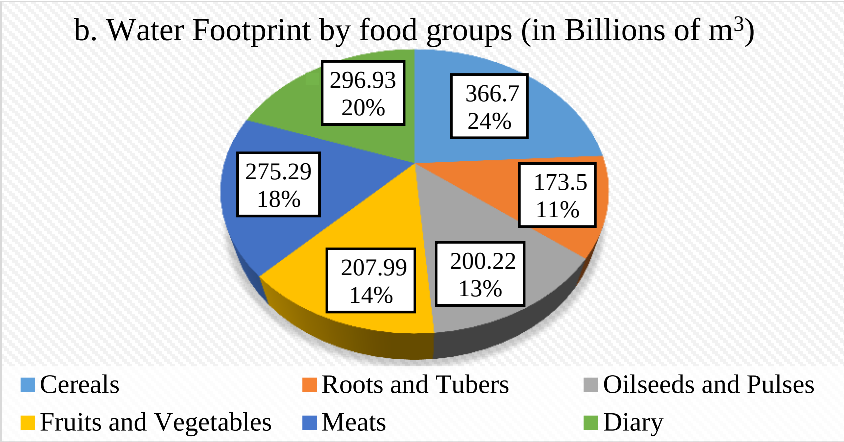
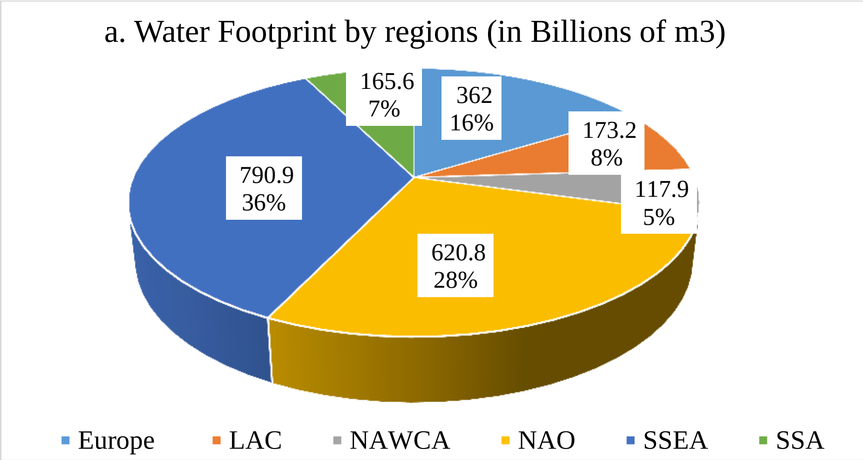


Figure 15. Water footprints from lost and wasted food at the 50% reduction level by a) regions and b) food groups



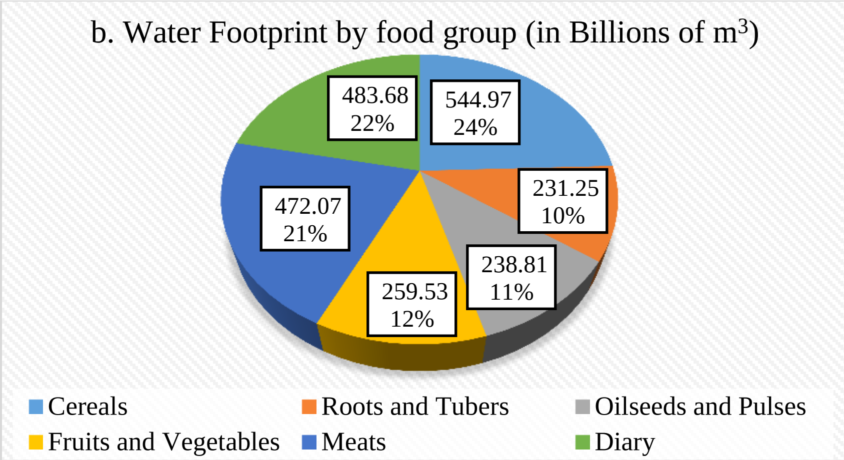


Figure 16. Water footprints from lost and wasted food at the lowest achieved reduction level by a) regions and b) food groups

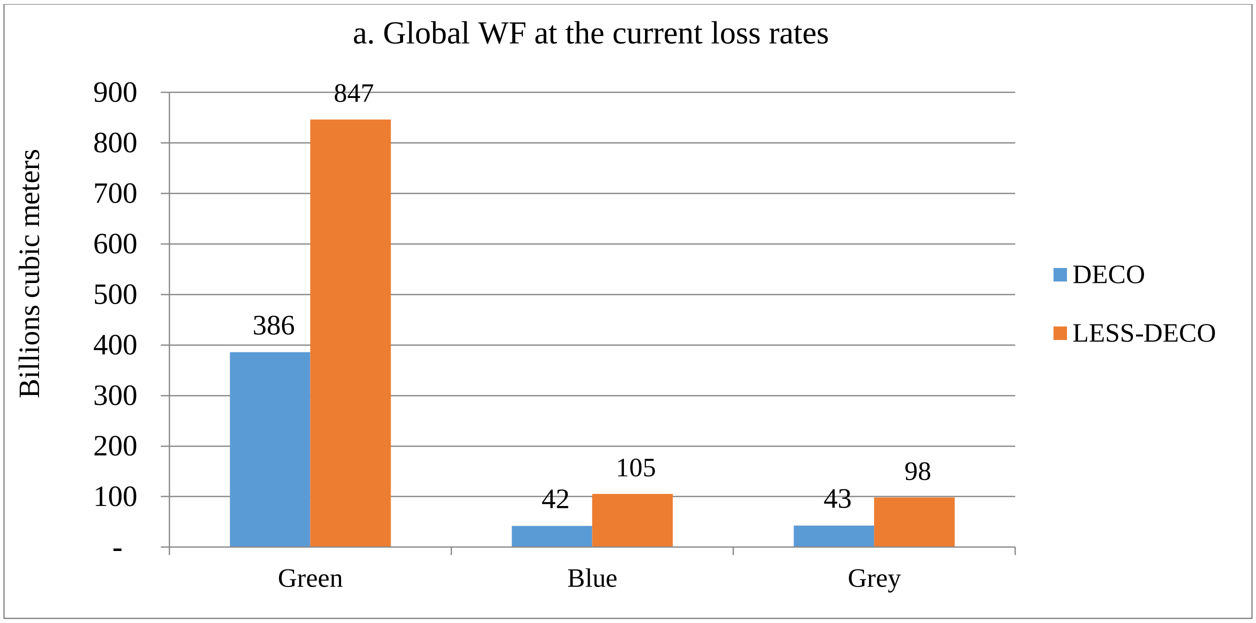


Figure 17. Global water footprint, comparison between developed and less developed regions at the current loss rates

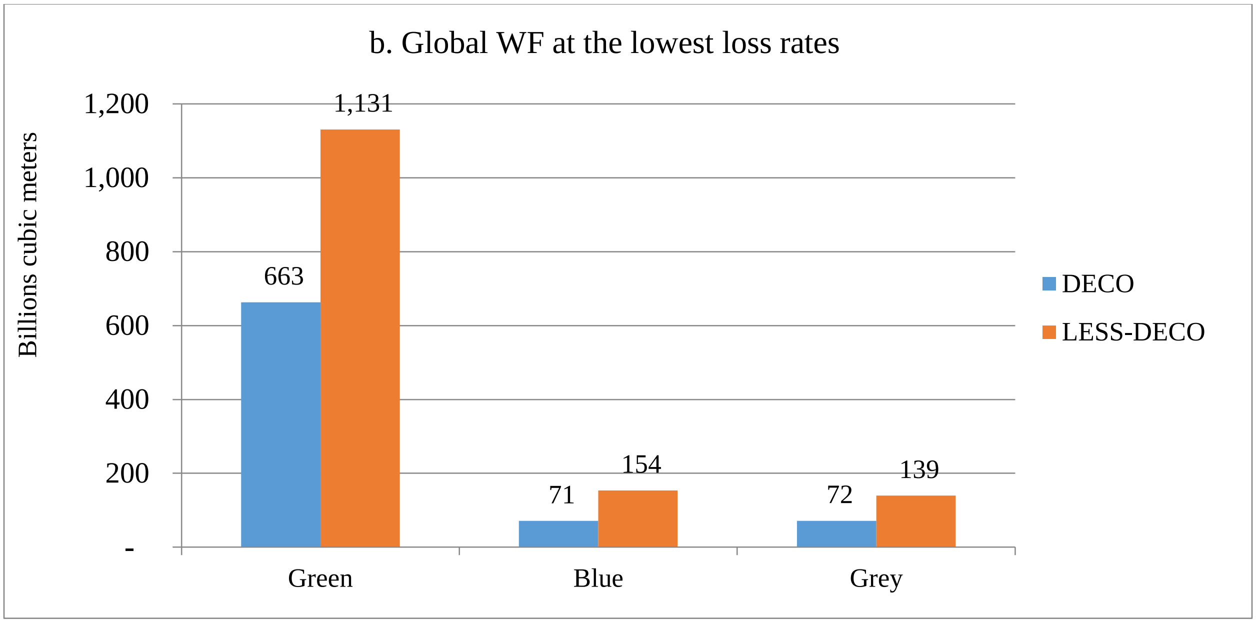


Figure 18. Global water footprint, comparison between developed and less developed regions at the lowest loss rates

4.4. Land resources used for producing wasted and lost food in both scenarios

Using the country yield levels of each crop/food type as indicators of how much land was used to produce lost and wasted food in each region, reveals that SSA and industrialized Asia would save more land resources than all other regions (Figure 19a). Halving food losses and wastes in 2013 using current loss rates would save approximately 116 and 231 million hectares, for SSA and Industrialized Asia, respectively, followed by Europe with 93 million hectares. When calculated at the lowest achieved reduction level, however, Industrialized Asia would save more land than all other regions, approximately 360 million hectares, while Europe and SSA would save almost the same amount of land (142 and 144 million hectares, respectively) (Figure 19b).

A comparison of less developed and developed regions shows that less developed regions lost more than six times as much land resource as developed regions in both scenarios (Figure 21). Figure 20 shows that cereals under both scenarios was the crop type leading to the most lost and wasted land through food losses and wastes.

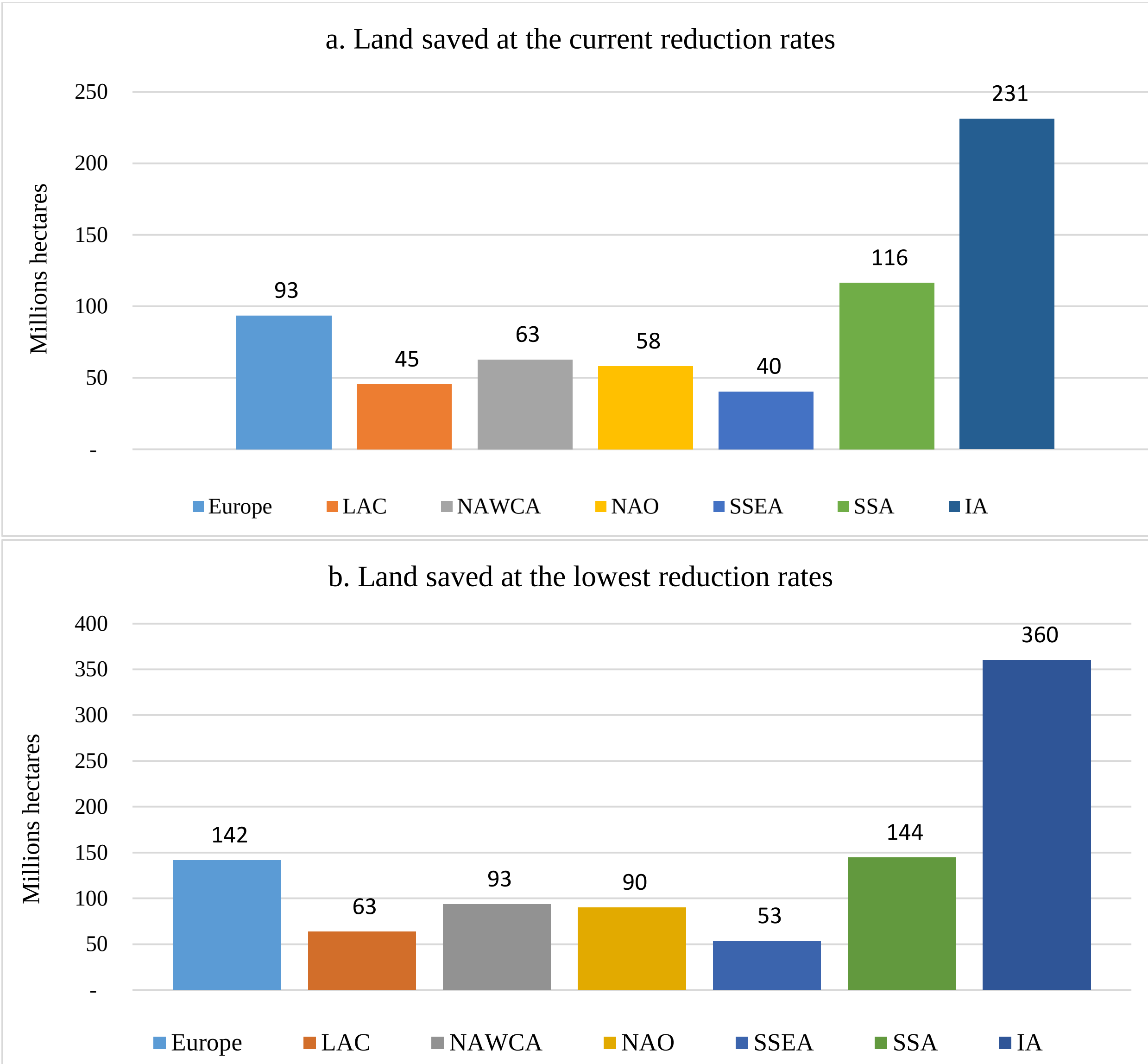


Figure 19. Land resources from lost and wasted food by regions at a) current loss rate and b) the lowest achieved reduction levels

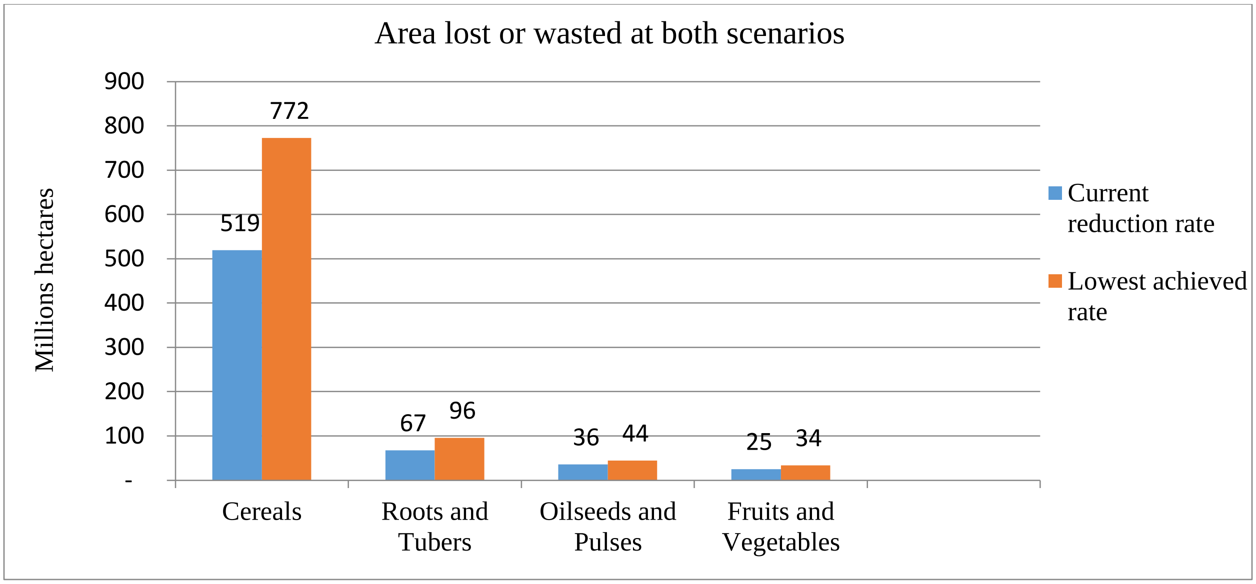


Figure 20. Land resources from lost and wasted food by food types in both scenarios

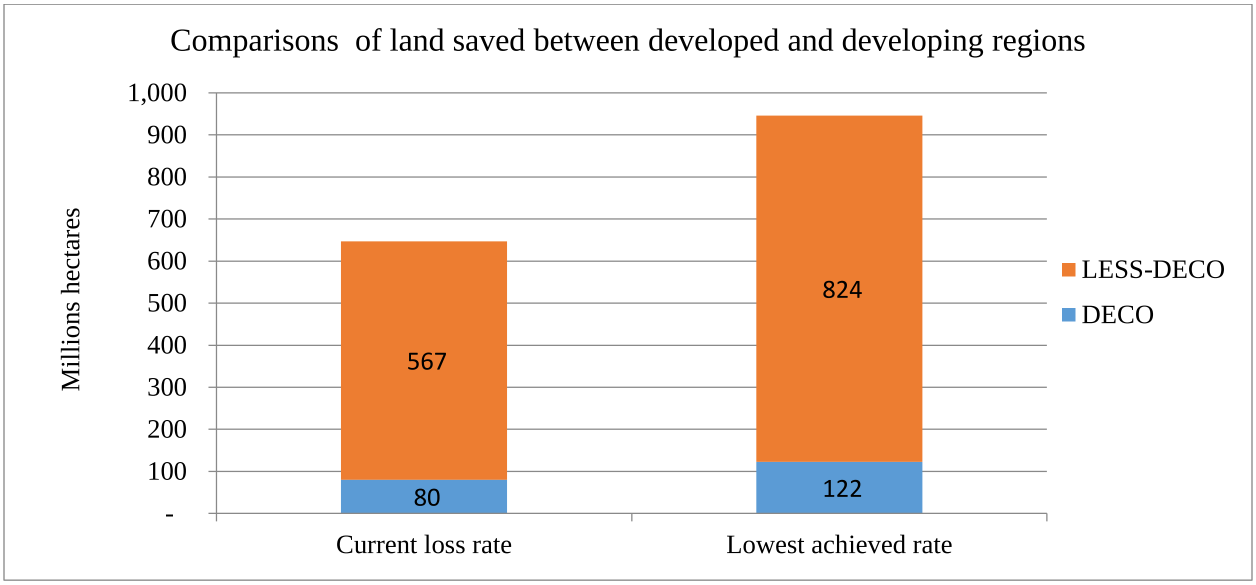


Figure 21. Land savings comparison between developed and less developed regions

4.5. Fertilizers used for producing wasted and lost food in both scenarios

Figure 22 shows the amount of fertilizer used to produce lost and wasted food and draws a comparison between regions for both scenarios. The results indicate that in either scenario Industrialized Asia lost and wasted more fertilizer than all other regions, accounting for approximately 74 million tons, followed by Europe, NAWCA, LAC, SSEA, NAO and SSA with approximately 10, 8, 7, 7, 7 and 2 million tons, respectively (Figure 22a). This amount increased when analyzing fertilizer losses at the lowest rate (Figure 22b).

The crop level analysis shows that cereal production led to more fertilizer losses than all other food types combined, followed by roots and tubers in both scenarios and in both developed and less developed regions (Figure 23). Figure 24 provides a comparison of fertilzer losses between developed and less developed regions. Just like the land and water footprint, less developed regions lost more fertilizer through food losses and wastes than developed regions. This was the case in both reduction scenarios. As rate changed from the current loss to the lowest loss scenario, less developed regions lost 114 and 172 million tons of fertilizer, respectively, while developed regions only lost approximately 12 and 19 million tons.

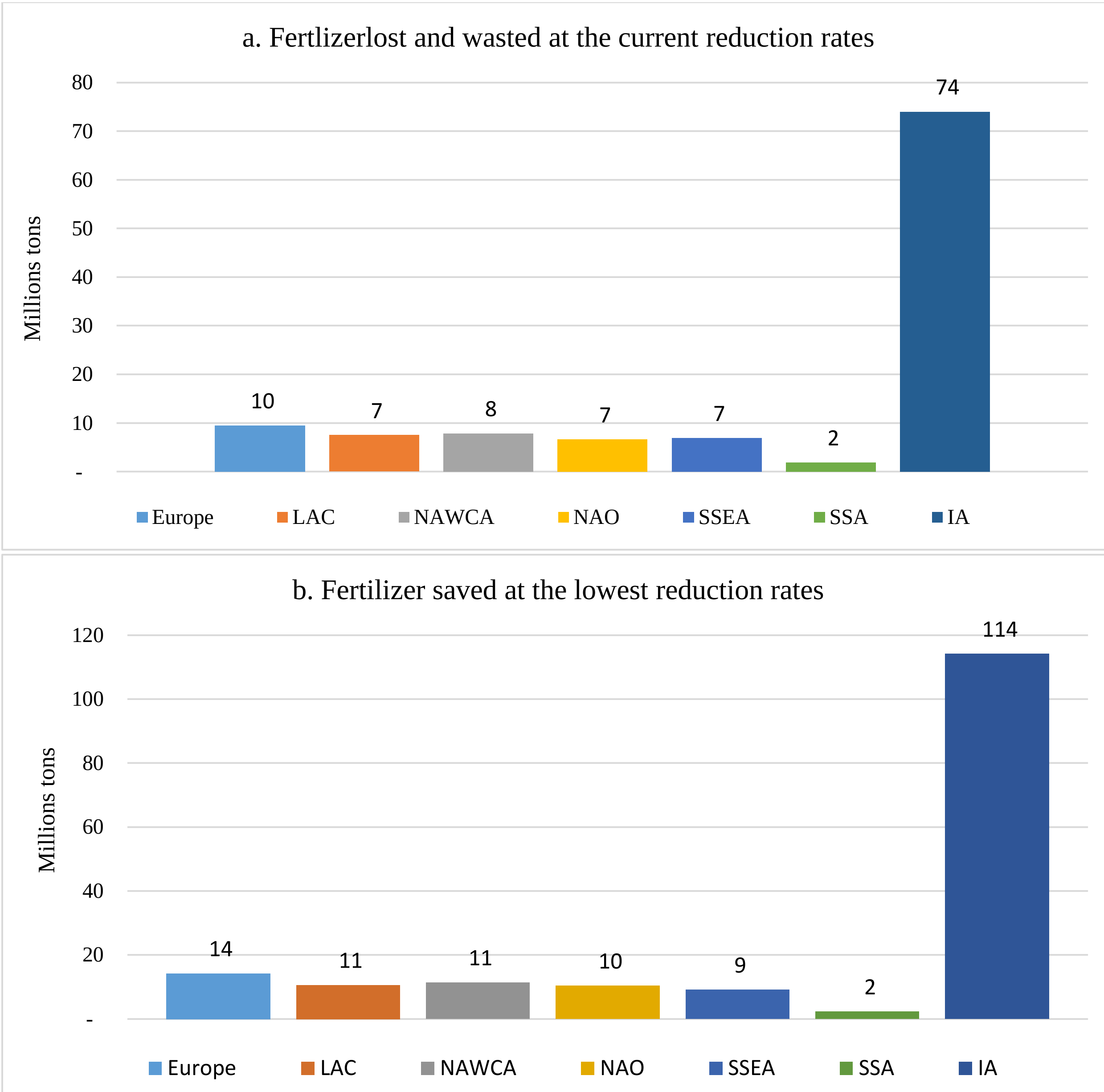


Figure 22. Fertilizer resources from lost and wasted food by regions a) current loss rate and b) the lowest achieved reduction levels

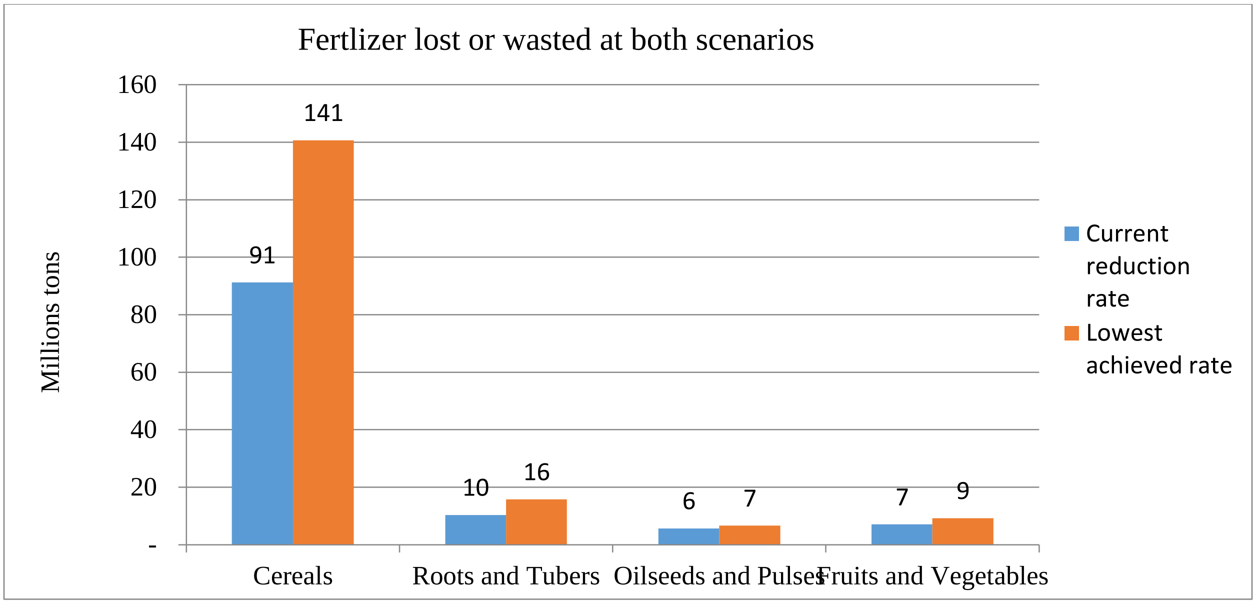


Figure 23. Fertilizer from lost and wasted food by food types.

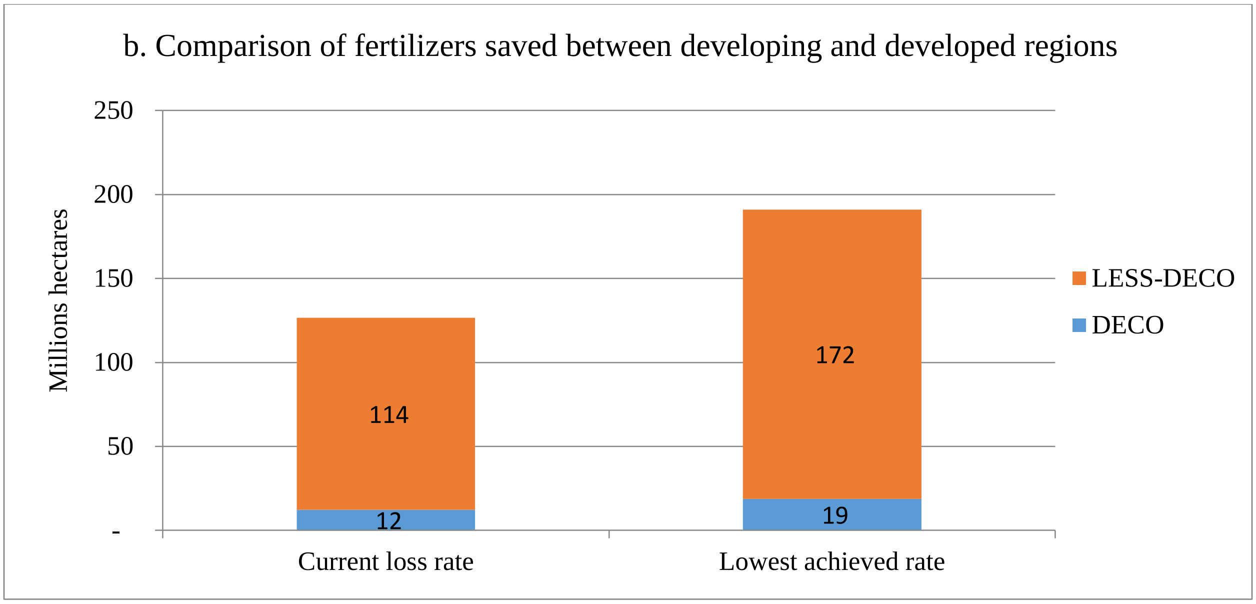


Figure 24. Fertilizer savings compared between developed and less developed regions

4.6. Discussions of results

Despite less developed regions losing more food than developed regions, a majority of the studies available on this topic assess developed regions onlyand focus more on food waste (e.g., Xue et al. (2017)).This could lead to a misdiagnosis of the problem of food losses and wastes and the steps being taken to solve such a problem.if this reduction was to be acchieved, food insecurity within many of the regions/countries in less developed region could be reduced significantly while decreasing dependency on food imports and food aid. Furthermore, as the global population is poised to exceed 9.5 billion people in 2050, this reduction could significantly decrease the amount of food that needs to be produced in the next 30 years.

It is not surprising that some of the less developed regions had the lowest per person quantities of food available from reducing food losses and wastes. Regarding food calories availability, SSA lost more roots and tubers, while all other regions are relatively more balanced with fruits and vegetables, dairy, meats and cereals. This suggests that roots and tubers are grown in relatively larger quantities than other categories of food in this region, despite their lower nutrition contents. The good news is that there is already ongoing efforts to increase nutritional contents of some roots and tubers such as cassava and orange fleshed sweet potatoes and to make vitamin A-rich rice available in many less developed regions, SSA included. However, efforts to make these available need to include farmers in SSA and other less developed regions in terms of their participation both in the research and in growing this food.

The amount of resources used to produce the lost and wasted food also provides an incentive in both regions of this study to reduce food losses and food wastes given its effects on resources. In less developed regions, the losses were many times more than those of developed regions, yet the production was much lower. This provides an opportunity for investments in better technologies and innovations throughout the food production and supply chain. This is especially important because proper management of the current land in agriculture, fertilizer use, or both could feed current global populations without the need to use more land and water resources. Results of this study also suggest that land and water resources are not being managed optimally, especially in the regions in which there is more water and land used but very low quantities of food produced.

The available data on this issue are still limited in several ways. First, a large amount of data are missing. While many countries in SSA were included, data were missing for countries that have seen wars and political instabilities. Unfortunately, these are some of the largest countries in the region with more land already in agriculture or with land that could be brought into agriculture (e.g., Democratic Republic of the Congo, Sudan, South Sudan, Eritrea, Somalia, Equatorial Guinea, Libya). This provides two areas of concern: the first is the possibility of underestimating what is actually lost and wasted in some regions. Given this lack of data, regions classified as less developed may be experiencing more losses than are estimated in this study. To minimize the level of underestimation or overestimation of food insecurity in this region, food insecure people from countries not represented in the data were also removed during the calculations of food insecurity for the region in which they belong.

In addition, studies on the subject of food losses and food wastes have generally focused on food losses in less developed regions and food wastes in developed regions (Balaji and Arshinder, 2016; Naziri et al., 2014), leading to an assumption that the current numbers may be below the actual quantities of food lost in developed regions and food wasted in less developed regions. If no effort is made to collect accurate and up to date information in less developed regions, efforts to solve the problem of hunger in this region may keep focusing on the wrong issues. It may be that they produce enough, but manage it poorly. Without data, it is easier to focus on more production when all that is needed is proper management of current production levels. Despite the limited data in these areas, however, the results of the study indicate that collecting data may actually confirm the above assumptions that, more losses may be incured in developed regions and more wastes in less developed regions than are being presented currently.

The findings of this study are similar to previous studies in terms of quantities of food lost and wasted and in their nutritional equivalency. FAO (2011) found that 1.3 billion tons of food stuff were lost and wasted in 2007 and about 1.5 quadrillion kilocalories in 2009 were lost or wasted. In this study, the estimate was 1.55 billion tons of food and 3.067 quadrillion kilocalories. These differences can be explained partially by the years covered in data and types of food involved in both studies.

In terms of natural resource use, the findings of this study are very similar to previous studies at the global level. Kummu et al. (2012) and Munesue et al. (2015), for example, reported that globally, approximately 250 km^3 of surface and fresh water, and 1.4 billion hectares of land are used to produce uneaten food. In this study, the total amount of water used to produce lost and wasted food is approximately between 304 km^3 for and 446 km^3 for both scenarios in this study. The amount of land used to produce the lost and wasted food was approximately between, 1.295 billion and 1.893 billion hectares of land in both scenarios.

Most of the data used in the study were aggregated already into much larger sub-groups that make it difficult to draw very specific conclusions. Data on fertilizer use, for example, were simply specified as fertilizers with no way to identify the type of fertilizer applied in what country and for which crop type. In terms of land, the data do not identify how many acres in each country were employed to produce individual crops/food type. For this reason, this study used the quantities produced and data on yield in each country by crops to estimate the amount of land and fertilizer used. This made it difficult to see how far the estimates of the study were from the official quantities of fertilizers and areas used in food production.

4.7. Other limitations of the study

This study did not include the effects of trade on food insecurity which can affect prices and incomes in global and local markets, imports, exports, taxes and tariffs on the quantities of food traded. Further research is warranted because trade plays an important factor in the global food systems, especially when it comes to countries that are net food impoters and countries that are producing specifically for exports. In addition, the study did not estimate the effects of continued growth in energy production or the crops that could be used for human consumption. As such this study is careful in making any assertions about these important areas. Instead, it focuses on the increase in availability of food as one of the tenets of food security. Therefore, the results and conclusions in this study can only be viewed in a form of increased availability of food in quantities and calories as a result of reductions in losses and wastes and the resulting reductions in resources used to produce them.

The FAO (2014) mentions the difficulties in determining certain effects of available energy through calories consumed for everyone because these can be different based on age, gender, body weight, and activity level, as well as pregnant and lactating women. Even after accounting for those differences, there remains the problem of fluctuations in individual requirements due to the efficiency of energy utilization among individuals. Since the variations from the average energy requirement is unknown, a constant level of energy required by region was assumed. This may overestimate or underestimate the number of undernourished if some nations have more children than adults who are food insecure and vice versa, since no data exist for the number of food insecure people in each country by age, gender, weight or activity level.

This study applies rates provided by Gustavsson et al. (2011) but these are limited in a number of ways. The first limitation arises from the fact that these rates are applied to geographically very large areas that are likely to be very different in many ways and depend on assumption made to reach these rates. Further studies are needed to provide loss and waste rates for smaller geographical areas that share characteristics within the countries.

A comparison of the rates at which food is being lost versus wasted suggests that a 50% reduction is feasible for some regions that others, at some stages and for some food types, by simply making the available technologies accessible in all regions and making other adjustments based on best management methods used elsewhere. For instance, regions of NAO and Europe lost a maximum of 18.5% of cereal before the consumption stage while this was at 28% in NAWCA. Meat losses were at a maximum of 3.5% in NAO, and Europe at the production stage, yet this was at 15% in SSA. Also, NAO wasted 28% of fruits and vegetables at consumption level, this rates was at 5%, 12%, 7%, and 10% for SSA, NAWCA, SSEA, and LA respectively, for fruit and vegetables. These examples suggest that they are rooms for regions to halve their losses or their wastes. However, achieving a 50% reduction depends on many factors, which will be different from region to region, country to country, zones within countries, income levels, production levels, technology advances, and political, academic, and public's willingness, ability and attitudes towards reducing food losses and wastes.

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

The goal of this study was to quantify and estimate the effects of halving the levels of food losses and wastes in less developed and developed countries on their food security, water, fertilizer and land resource use. The study applied two levels of food wastes and losses: 1) the currently estimated loss and wastes rates provided in the appendix A (Gustavsson et al., 2011) and applying them to the food quantities available at different stages of the food chain using data from FAOSTAT (2013) and 2) the lowest achieved loss and waste rates applied to all regions. The quantities obtained after applying the rates were assumed to be the total quantities lost and wasted, and then a 50% reduction was applied to ensure that all lost and wasted quantities were reduced by half. These reduced values were then used to calculate resources needed to produce the halved quantities.

The results of this study indicate that halving the current global food losses and wastes can make available enough food to feed more than twice the number of people considered food insecure in 2013 without the need to produce more. This leads to the conclusion that the overemphasis on increasing production may be unwarranted. Given that there is enough food for everyone, agricultural policy makers should consider what is available first and not simply how many people will be here soon and how much is needed to feed them. In addition, it is recommended that efforts to reduce waste prioritize countries and regions where that food is needed most (i.e., Sub-Saharan Africa and South and South East Asia).

The results of regional comparison showed that all regions would be able to feed their food insecure people except SSA which would only save enough to feed approximately 87% of their food insecure people in 2013 using halved savings from their current lost and wasted food scenario. It is recommended that more effort be directed towards redistribution of this food through programs like food aid, food stamps (directed towards food purchases only), Women, Infants and Children (WIC) programs, and grocery store donations to people and institutions working to provide food to all who need it. But for a region like SSA, this may require more efforts than other regions in order to increase their food availability. These could include increasing food production through better yielding crop varieties in conjunction with reducing their food losses at the lowest reduction levels achieved which would provide more than enough food for all.

Given the quantities of global food losses and wastes in this study and the number of people who could be fed by simply reducing them there may be no need to bring more land into agriculture or at least not as much as has been suggested by some (Foley et al., 2011; FAO, 2011). Instead, regions facing the highest numbers of food insecurity should focus on investing in efficient technologies, applying best agricultural practices, creating better financial capital for farmers, maintaining up-to-date market information, providing better storage facilities and generally ensuring better management of what is already being employed and produced, preferably at the subsistence or household levels.

Assuming that reducing food losses and wastes is more cost effective, than producing more food to offset losses (FAO, 1981), reducing food loss and food waste should take priority in the effort to fight hunger and food insecurity. This will be more important as global income levels are expected to increase, and the emerging and less developed economies embrace new diets and a culture of consumerism, contributing to an increase of food losses and wastes (Xue et al., 2017). The less developed regions may still have a chance to incorporate ideas of no wastes into their food policies and systems (Beverland, 2014; Reisch et al., 2013; Thorgersen, 2014) before their production capabilities begin to encourage trends, behaviors, and transitions that can lead to more food wastes (Scafiee-jood and Cai, 2016).

The results reveal that at the national and regional level, some of the least covered nations on this issue actually lost more food and resources. This was true when comparing developed and less developed regions. Moreover, the losses and wastes at the food type levels suggest that some regions (e.g. SSA) produce more of the food types that require many resources and provide little in terms of quantities and nutrition. This also emphasizes the need to increasing food production through better yielding crop varieties and food types that provide more nutritional value.

Concerted efforts are needed in all countries to compile data in order to have a full picture of this problem, especially in regions that have the most hungry (i.e., Sub-Saharan Africa, and South and South Eastern Asia, and Latin America).This is especially important because the available data do not necessarily break into seasonal availability, but are compiled annually. Access to seasonal data would help researchers and policy makers identify local, national and regional food insecurity outbreaks and improve planning for them.

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APPENDINCES

Appendix A

The following Tables A-1 through A-6 are adopted from Gustavsson et al.(2013) unchanged while Table A-7 has been changed to select the lowest food loss and waste rates, if all nations were to reduce their losses and wastes to the lowest rates achieved anywhere else.

Table A-1. The rates of losses and wastes by commodity groups and food chain stages in Europe and Russia

	Agricultural Production	Postharvest handling and storage	Processing and packaging	Distribution: Supermarkets and retail	Consumption
Cereals	2%	4%	0.5% & 10%	2%	25%
Roots and Tubers	20%	9%	15%	7%	17%
Oilseeds and Pulses	10%	1%	5%	1%	4%
Fruits and Vegetables	20%	5%	2%	10%	19%
Meats	3.1%	0.7%	5%	4%	11%
Milk & other dairy	3.5%	0.5%	1.2%	0.5%	7%

Table A-2. The rates of losses and wastes by commodity groups and food chain stages in North America and Oceania

	Agricultural Production	Postharvest handling and storage	Processing and packaging	Distribution: Supermarkets and retail	Consumption
Cereals	2%	2%	0.5% & 10%	2%	27%
Roots and Tubers	20%	10%	15%	7%	30%
Oilseeds and Pulses	12%	0%	5%	1%	4%
Fruits and Vegetables	20%	4%	2%	12%	28%
Meats	3.5%	1.0%	5%	4%	11%
Milk & other dairy	3.5%	0.5%	1.2%	0.5%	15%

Table A-3. The rates of losses and wastes by commodity groups and food chain stages in Industrialized Asia

	Agricultural Production	Postharvest handling and storage	Processing and packaging	Distribution: Supermarkets and retail	Consumption
Cereals	2%	10%	0.5% & 10%	2%	20%
Roots and Tubers	20%	7%	15%	9%	10%
Oilseeds and Pulses	6%	3%	5%	1%	4%
Fruits and Vegetables	10%	8%	2%	8%	15%
Meats	2.9%	0.6%	5%	6%	8%
Milk & other dairy	3.5%	1%	1.2%	0.5%	5%

Table A-4. The rates of losses and wastes by commodity groups and food chain stages in Sub-Saharan Africa

	Agricultural Production	Postharvest handling and storage	Processing and packaging	Distribution: Supermarkets and retail	Consumption
Cereals	6%	8%	3.5%	2%	1%
Roots and Tubers	14%	18%	15%	5%	2%
Oilseeds and Pulses	12%	8%	8%	2%	1%
Fruits and Vegetables	10%	9%	25%	17%	5%
Meats	15%	0.7%	5%	7%	2%
Milk & other dairy	6%	11%	0.1%	10%	0.1%

Table A-5. The rates of losses and wastes by commodity groups and food chain stages in North Africa, West & Central Asia

	Agricultural Production	Postharvest handling and storage	Processing and packaging	Distribution: Supermarkets and retail	Consumption
Cereals	6%	8%	2% & 7%	4%	12%
Roots and Tubers	6%	10%	12%	4%	6%
Oilseeds and Pulses	15%	6%	8%	2%	2%
Fruits and Vegetables	17%	10%	20%	15%	12%
Meats	6.6%	0.2%	5%	5%	8%
Milk & other dairy	3.5%	6%	2%	8%	2%

Table A-6. The rates of losses and wastes by commodity groups and food chain stages in South and Southern Asia

	Agricultural Production	Postharvest handling and storage	Processing and packaging	Distribution: Supermarkets and retail	Consumption
Cereals	6%	7%	3.5%	2%	3%
Roots and Tubers	6%	19%	10%	11%	3%
Oilseeds and Pulses	7%	12%	8%	2%	1%
Fruits and Vegetables	15%	9%	25%	10%	7%
Meats	5.1%	0.3%	5%	7%	4%
Milk & other dairy	3.5%	6%	2%	10%	1%

Table A-7. The rates of losses and wastes by commodity groups and food chain stages in Latin America

	Agricultural Production	Postharvest handling and storage	Processing and packaging	Distribution: Supermarkets and retail	Consumption
Cereals	6%	4%	2% & 7%	4%	10%
Roots and Tubers	14%	14%	12%	3%	4%
Oilseeds and Pulses	6%	3%	8%	2%	2%
Fruits and Vegetables	20%	10%	20%	12%	10%
Meats	5.3%	1.1%	5%	5%	6%
Milk & other dairy	3.5%	6%	2%	8%	4%

Table A-8. Lowest rates scenario for food wastes and losses applied to all regions

	Agricultural Production	Postharvest handling and storage	Processing and packaging	Distribution: Supermarkets and retail	Consumption
Cereals	2%	2%	0.5%, 7%	2%	1%
Roots and Tubers	6%	7%	10%	3%	2%
Oilseeds and Pulses	6%	1%	5%	1%	1%
Fruits and Vegetables	10%	4%	2%	8%	5%
Meats	2.9%	0.3%	5%	4%	2%
Milk & other dairy	3.5%	0.5%	0.1%	0.5%	0.1%

Table A-9. Water Footprint of the current lost and wasted food by regions

	Billion cubic meters (m^3)			
Regions	**Green**	**Blue**	**Grey**	**Total**
Europe	215.137	28.782	28.276	272.195
LAC	130.019	8,871	8.695	147.585
NAWCA	69.134	13,169	8.867	91.170
NAO	265.722	25,668	27.155	318.546
SSEA	430.187	65,411	60.706	556.305
SSA	122.079	5,477	7.274	134.831
DECO	385.726	41,927	42.710	470.365
LESS-DECO	846.553	105,453	98.263	1,050.270
Total Global Water Footprint	1,232.279	147,381	140.974	1,520.635
Percent by Categories	81.0	9.7	9.3	

Table A-10. Water Footprint of the lowest achieved reduction rate in food loss and waste by regions

	Billion cubic meters (m^3)			
Regions	**Green**	**Blue**	**Grey**	**Total**
Europe	329.240	44.795	43.466	417.502
LAC	149.183	12.179	11.790	173.153
NAWCA	85.892	19.335	12.643	117.871
NAO	472.398	45.466	47.450	565.315
SSEA	608.095	96.169	86.632	790.897
SSA	149.470	6.958	9.141	165.570
DECO	663.143	71.036	71.653	805.833
LESS-DECO	1,131.137	153.868	139.469	1,424.476
Total Global Water Footprint	1,794.281	224.905	211.123	2,230.309
Percent by Categories	80.4	10.1	9.5	

Table A-11. Water Footprint from the current lost and wasted food by crops

	Billion cubic meters (m^3)			
Food types	**Green**	**Blue**	**Grey**	**Total**
Cereals	270.883	54.720	41.096	366.700
Roots and Tubers	144.969	9.065	19.463	173.498
Oilseeds and Pulses	178.394	9.999	11.826	200.220
Fruits and Vegetables	143.437	34.069	30.487	207.994
Meats	243.628	14.603	17.059	275.291
Dairy	250.966	24.921	21.041	296.929
Total Global Water Footprint	1,232.279	147,381	140.974	1,520.635
Percent by Categories	81.0	9.7	9.3	

Table A-12. Water Footprint of the lowest reduction rate in food loss and waste by Crops

	Billion cubic meters (m^3)			
Food types	**Green**	**Blue**	**Grey**	**Total**
Cereals	396.442	86.406	62.120	544.968
Roots and Tubers	188.184	13.753	29.308	231.246
Oilseeds and Pulses	210.992	12.909	14.907	238.810
Fruits and Vegetables	171.877	46.381	41.270	259.529
Meats	417.920	24.887	29.266	472.073
Dairy	408.864	40.566	34.249	483.680
Total Global Water Footprint	1,794.281	224.905	211.123	2,230.309
Percent by Categories	80.4	10.1	9.5	

Appendix B

The FAO methodology for estimating the proportion of food insecure people

The proportion of individuals considered undernourished in the total population was defined by the following probability distribution (FAO, 2008, FAO, 2014):

$$P(U) = P(x < r_L) = \int_{x < r_L} f(x)dx = F_x(r_L) \tag{16}$$

Where P(U) is the proportion of undernourished in the total population, (x) refers to the dietary energy consumption, r_L is a cut-off point representing the minimum energy requirement, f(x) is the density function of dietary energy consumption, and F_x is the cumulative distribution function.

A summarized description of the procedure for calculating the prevalence of undernourishment on the basis of *x*, the Coefficient of Variation of (x) (CV(x)), and r_L applied to a hypothetical country as an example can be found in FAO, (2008). In this study, it was assumed that the Dietary Energy Supply (DES) represents the regional mean caloric requirements in kcal per person per day and the Minimum Dietary Energy Requirement (MDER) represents a cut-off point (r_L) in each region (FAO, 2017). Since FAO, (2017) provides these data by country, the regional average for the period of 2011- 2013 was used in each case to represent the DES and MDER. The CV(x) was estimated as:

$$CV(x) = \sqrt{CV^2(x|v) + CV^2(x|r)} \tag{17}$$

where CV(x) is the total coefficient of variations of the household daily per person dietary energy consumption, CV ($x|v$) is the component due to household per person daily income (v) and CV ($x|r$) is the component due to energy requirement (r). CV ($x|r$) is considered to be a fixed component and is estimated to be about 0.20 (FAO, 2008). CV ($x|v$) is, however, estimated on the basis of FAO's household survey data (FAO, 2014) and is estimated as:

$$CV(x|v) \ = \ \sigma(x|v) \ / \ \mu_x$$

Where

$$\sigma(x|v) = \ \sqrt{\left[\sum_{j=1}^{k} f_j(x|v)_j^2 - (\sum_{j=1}^{k} \frac{f_j(x|v)_j)^2}{n}\right] / (n-1)} \quad (18)$$

and

$$\mu_x = \ \sum(x) \ / \ n \quad (19)$$

where k is the number of income classes, f_j is the number of sampled households, and *(x|v) j* is the average household daily per person dietary energy consumption of the j_{th} income or expenditure class.

The density function of dietary energy consumption, f(x), is assumed to be lognormal with parameters μ_x and σ_x^2. These parameters are estimated on the basis of the mean $\bar{x}$ and coefficient of variation *CV*(x) as follows:

$$\sigma_x = \left[log_e\left(\left(CV(x)\right)^2 + 1\right)\right]^{1/2} \quad (20)$$

and

$$\mu_x = \log_e \bar{x} - \sigma^2/2 \tag{21}$$

The proportion of population below the cut-off point was estimated as:

$$\Phi[(\log_e r_L - \mu)/\sigma] \tag{22}$$

where Φ is the standard normal cumulative distribution.

Finally, the number of people facing food insecurity was determined by multiplying the proportion of undernourished people with the size of the reference population in each region, adjusted to ensure that all available calories are consumed and everyone has access to the regional cut-off point.

The DES is computed using the Food Balance Sheets from FAO, while the MDER is computed as a weighted average of energy requirements accounting for differences due to sex and age, which is updated annually from UN population ratio data (FAO, 2014). This study had no access to data of how many food insecure people are children versus adults, male versus female, pregnant versus lactating women, or the activity levels of each one. Therefore, the daily per capita caloric supply data for all nations for the period of 2011-2013 (FAO, 2017) were used to compute the regional average to represent both the MDER and DES. Those averages were then applied to everyone in that region.

VITA

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